# The State of Coral Reef Ecosystems of the United States and Pacific Freely Associated States: 2008

Produced by the National Oceanic and Atmospheric Administration,
in cooperation with partners from Federal, State, Territorial and
Commonwealth Agencies, and the Pacific Freely Associated States.

QH
541.5
.C7
S7
2008
c.1

NOAA Technical Memorandum NOS NCCOS 73

DEPARTMENT OF COMMERCE • UNITED STATES OF AMERICA

## CITATIONS:

Citation for the entire document:

Waddell, J.E. and A.M. Clarke (eds.), 2008. The State of Coral Reef Ecosystems of the United States and Pacific Freely Associated States: 2008. NOAA Technical Memorandum NOS NCCOS 73. NOAA/NCCOS Center for Coastal Monitoring and Assessment's Biogeography Team. Silver Spring, MD. 569 pp.

Example citation for an individual chapter (example of Navassa Island chapter):

Miller, M.W., A. Gleason, D. McClellan, G. Piniak, D. Williams, J.W. Wiener, A. Gude, J. Schwagerl. 2008. The State of Coral Reef Ecosystems of Navassa Island. pp. 117-129. In: J.E. Waddell and A.M. Clarke (eds.), The State of Coral Reef Ecosystems of the United States and Pacific Freely Associated States: 2008. NOAA Technical Memorandum NOS NCCOS 73. NOAA/NCCOS Center for Coastal Monitoring and Assessment's Biogeography Team. Silver Spring, MD. 569 pp.

## ACKNOWLEDGEMENTS:

The production of this report would not have been possible without the participation of the people recognized below. Their efforts to help compile, format, edit, and review the document are very much appreciated. Particular recognition goes to Alicia Clarke, who formatted the figures and tables in the document and Kenneth Buja, who created the maps.

Additional editorial and support staff include:
Laurie Bauer, Kenneth Buja, Chris Caldow, John Christensen, Lawrence Claflin, Alicia Clarke, James Connors, Tracy Gill, Zach Hecht-Leavitt, Sarah Hile, Jamison Higgins, Christopher Jeffrey, Matt Kendall, Kevin McMahon, Charles Menza, Mark Monaco, David Moe Nelson, Simon Pittman, Kimberly Woody and Adam Zitello.

## FOR MORE INFORMATION:

For more information about this report or to request a copy, please contact NCCOS CCMA's Biogeography Branch at 301-713-3028 or visit http://ccma.nos.noaa.gov/about/biogeography/.

This report and previous reports in the series are available in PDF format via a free internet download from http://ccma.nos.noaa.gov/stateofthereefs.

## DISCLAIMER:

This publication does not constitute an endorsement of any commercial product or intend to be an opinion beyond scientific or other results obtained by the National Oceanic and Atmospheric Administration (NOAA). No reference shall be made to NOAA, or this publication furnished by NOAA, in any advertising or sales promotion which would indicate or imply that NOAA recommends or endorses any proprietary product mentioned herein, or which has as its purpose an interest to cause directly or indirectly the advertised product to be used or purchased because of this publication.

“Year of the Reef” by Wyland. Used with artist's permission.

NMFS Honolulu Library
*000000000005546*

# The State of Coral Reef Ecosystems of the United States and Pacific Freely Associated States: 2008

QH
541.5
.C7
S7
2008
c.1

**Report coordinators by jurisdiction:**

**U.S. Virgin Islands**–J. Paige Rothenberger
**Puerto Rico**–Jorge García-Sais
**Navassa Island**–Margaret W. Miller
**Southeast Florida**–Chantal Collier
**Florida Keys**–Scott Donahue
**Flower Garden Banks**–Emma Hickerson
**Main Hawaiian Islands**–Alan Friedlander
**Northwestern Hawaiian Islands**–Alan Friedlander
**American Samoa**–Douglas Fenner
**Pacific Remote Island Areas**–Joyce Miller
**Republic of the Marshall Islands**–Maria Beger, Dean Jacobson
**Federated States of Micronesia**–Alissa Takesy
**Commonwealth of the Northern Mariana Islands**–John Starmer
**Guam**–David Burdick
**Republic of Palau**–Sebastian Marino

**Additional contributors:**
Alicia Clarke, Elizabeth Dieveney, Dwight Gledhill, Meghan Gombos, Chris Jeffrey, Jennifer Koss, Trina Leberer, Gang Liu, Christy Loper, Jennifer Moore, Jessica Morgan, Shannon Simpson, Dana Wusinich-Mendez

NOAA Technical Memorandum
NOS NCCOS 73
April 2008

---

| United States Department of Commerce | National Oceanic and Atmospheric Administration | National Ocean Service |
|---|---|---|
| Carlos M. Gutierrez<br>Secretary | Vice Admiral Conrad C. Lautenbacher, Jr. USN (Ret.)<br>Administrator | John H. Dunnigan<br>Assistant Administrator |

---

# TABLE OF CONTENTS

Introductory Information
- Citations i
- Acknowledgements i
- Table of Contents iii–vi

Executive Summary 1

**Chapter 1**: National Level Activities **11**
Coral Reef Ecosystem Integrated Observing System 11
2005 Caribbean Coral Bleaching Event 16
Endangered Species Act Listing of Caribbean Corals in the Genus *Acropora* 16
Social Science and the Human Dimensions of Coral Reef Ecosystems 18
Improving the Use of Marine Protected Areas in Coral Reef Ecosystems 21
Micronesia Challenge 22
Coral Reef Ecosystem Conservation Amendment Act 24
Federal Fisheries Management 25
U.S. Coral Reef Task Force 10th Anniversary 26
International Year of the Reef 2008 27

**Chapter 2**: The State of Coral Reef Ecosystems of the U.S. Virgin Islands **29**
*Paige Rothenberger, Jeremiah Blondeau, Carrollyn Cox, Susan Curtis, William S. Fisher, Virginia Garrison, Zandy Hillis-Starr, Christopher F.G. Jeffrey, Elizabeth Kadison, Ian Lundgren, Jeff Miller, Erinn Muller, Richard Nemeth, Shona Paterson, Caroline Rogers, Tyler Smith, Anthony Spitzack, Marcia Taylor, Wesley Toller, Julie Wright, Dana Wusinich-Mendez and Jeannette Waddell*

Environmental and Anthropogenic Stressors 31
Coral Reef Ecosystem Data-Gathering Activities and Resource Condition 38
Water Quality and Oceanographic Conditions 40
Benthic Habitats 42
Associated Biological Communities 53
Current Conservation Management Activities 63
Overall Conclusions and Recommendations 67
References 69

**Chapter 3**: The State of Coral Reef Ecosystems of Puerto Rico **75**
*Jorge García-Sais, Richard Appeldoorn, Tim Battista, Laurie Bauer, Andy Bruckner, Chris Caldow, Lisamarie Carrubba, Jorge Corredor, Ernesto Diaz, Craig Lilyestrom, Graciela García-Moliner, Edwin Hernández-Delgado, Charles Menza, Julio Morell, Tony Pait, Jorge Sabater, Ernesto Weil, Ernest Williams and Stephanie Williams*

Environmental and Anthropogenic Stressors 78
Coral Reef Ecosystem Data-Gathering Activities and Resource Condition 95
Water Quality and Oceanographic Conditions 96
Benthic Habitats 97
Associated Biological Communities 106
Current Conservation Management Activities 110
Overall Conclusions and Recommendations 111
References 113

**Chapter 4**: The State of Coral Reef Ecosystems of Navassa Island **117**
*Margaret W. Miller, A. Gleason, D. McClellan, G. Piniak, D. Williams, J.W. Wiener, A. Gude, J. Schwagerl*

Environmental and Anthropogenic Stressors 118
Coral Reef Ecosystem Data-Gathering Activities and Resource Condition 120
Water Quality and Oceanographic Conditions 121
Benthic Habitats 121
Associated Biological Communities 127
Current Conservation Management Activities 128
Overall Conclusions and Recommendations 128
References 129

**Chapter 5**: The State of Coral Reef Ecosystems of Southeast Florida **131**
*Chantal Collier, Rob Ruzicka, Ken Banks, Luiz Barbieri, Jeff Beal, David Bingham, James Bohnsack, Sandra Brooke, Nancy Craig, Richard Dodge, Lou Fisher, Nick Gadbois, David Gilliam, Lisa Gregg, G.Todd Kellison, Vladimir Kosmynin, Brian Lapointe, Erin McDevitt, Janet Phipps, Nikki Poulos, John Proni, Patrick Quinn, Bernhard Riegl, Richard Spieler, Joanna Walczak, Brian Walker and Denise Warrick*

Environmental and Anthropogenic Stressors 134
Coral Reef Ecosystem Data-Gathering Activities and Resource Condition 140
Water Quality and Oceanographic Conditions 142
Benthic Habitats 143
Associated Biological Communities 146
Current Conservation Management Activities 149
Overall Conclusions and Recommendations 152
References 155

**Chapter 6**: The State of Coral Reef Ecosystems of the Florida Keys **161**
*Scott Donahue, Alejandro Acosta, Lad Akins, Jerald Ault, James Bohnsack, Joseph Boyer, Michael Callahan, Billy Causey, Carrollyn Cox, Joanne Delaney, Gabriel Delgado, Kent Edwards, George Garrett, Brian Keller, G. Todd Kellison, V. Robert Leeworthy, Lauri MacLaughlin, Loren McClenachan, Margaret W. Miller, Steven L. Miller, Kim Ritchie, Steven Rohmann, Deborah Santavy, Christy Pattengill-Semmens, Benjamin Sniffen, Stephen Werndli and Dana E. Williams*

Environmental and Anthropogenic Stressors 162
Coral Reef Ecosystem Data-Gathering Activities and Resource Condition 168
Water Quality and Oceanographic Conditions 169
Benthic Habitats 173
Associated Biological Communities 177
Current Conservation Management Activities 182
Overall Conclusions and Recommendations 185
References 186

**Chapter 7**: The State of Coral Reef Ecosystems of the Flower Garden Banks and Other Banks of the Northwestern Gulf of Mexico **189**
*Emma L. Hickerson, G.P. Schmahl, Martha Robbart, William F. Precht and Chris Caldow*

Environmental and Anthropogenic Stressors 191
Coral Reef Ecosystem Data-Gathering Activities and Resource Condition 197
Water Quality and Oceanographic Conditions 199
Benthic Habitats 200
Associated Biological Communities 205
Current Conservation Management Activities 214
Overall Conclusions and Recommendations 214
References 216

**Chapter 8**: The State of Coral Reef Ecosystems of the Main Hawaiian Islands **219**
*Alan Friedlander, Greta Aeby, Russell Brainard, Eric Brown, Kathy Chaston, Athline Clark, Petra McGowan, Tony Montgomery, William Walsh, Ivor Williams and Wendy Wiltse*

Environmental and Anthropogenic Stressors 221
Coral Reef Ecosystem Data-Gathering Activities and Resource Condition 237
Water Quality and Oceanographic Conditions 239
Benthic Habitats 241
Associated Biological Communities 247
Current Conservation Management Activities 250
Overall Conclusions and Recommendations 256
References 258

**Chapter 9**: The State of Coral Reef Ecosystems of the Northwestern Hawaiian Islands **263**
*Alan Friedlander, Greta Aeby, Seema Balwani, Brian Bowen, Russell Brainard, Athline Clark, Jean Kenyon, James Maragos, Carl Meyer, Peter Vroom and Jill Zamzow*

Environmental and Anthropogenic Stressors 265
Coral Reef Ecosystem Data-Gathering Activities and Resource Condition 276
Water Quality and Oceanographic Conditions 276
Benthic Habitats 279
Associated Biological Communities 291
Current Conservation Management Activities 300
Overall Conclusions and Recommendations 300
References 302

**Chapter 10**: The State of Coral Reef Ecosystems of American Samoa **307**
*Douglas Fenner, Meredith Speicher, Sharon Gulick, Greta Aeby, Susan Cooper Aletto, Paul Anderson, Benjamin Carroll, Eva DiDonato, Guy DiDonato, Virginia Farmer, Jameson Gove, Peter Houk, Emily Lundblad, Marc Nadon, Francesca Riolo, Marlowe Sabater, Robert Schroeder, Ellen Smith, Christianera Tuitele, Alden Tagarino, Selaina Vaitautolu, Elena Vaoli, Bernardo Vargas-Angel and Peter Vroom*

Environmental and Anthropogenic Stressors 310
Coral Reef Ecosystem Data-Gathering Activities and Resource Condition 317
Water Quality and Oceanographic Conditions 317
Benthic Habitats 321
Associated Biological Communities 330
Current Conservation Management Activities 342
Overall Conclusions and Recommendations 346
References 347

**Chapter 11**: The State of Coral Reef Ecosystems of the Pacific Remote Island Areas **353**
*Joyce Miller, Jim Maragos, Russell Brainard, Jacob Asher, Bernardo Vargas-Ángel, Jean Kenyon, Robert Schroeder, Benjamin Richards, Marc Nadon, Peter Vroom, Amy Hall, Elizabeth Keenan, Molly Timmers, Jamison Gove, Ellen Smith, Jonathan Weiss, Emily Lundblad, Scott Ferguson, Frances Lichowski and John Rooney*

Environmental and Anthropogenic Stressors 355
Coral Reef Ecosystem Data-Gathering Activities and Resource Condition 363
Water Quality and Oceanographic Conditions 364
Benthic Habitats 366
Associated Biological Communities 377
Current Conservation Management Activities 382
Overall Conclusions and Recommendations 383
References 384

**Chapter 12**: The State of Coral Reef Ecosystems of the Republic of the Marshall Islands **387**
*Maria Beger, Dean Jacobson, Silvia Pinca, Zoe Richards, Don Hess, Frankie Harriss, Cathie Page, Eric Peterson and Nicole Baker*

Environmental and Anthropogenic Stressors 389
Coral Reef Ecosystem Data-Gathering Activities and Resource Condition 396
Water Quality and Oceanographic Conditions 397
Benthic Habitats 397
Associated Biological Communities 407
Current Conservation Management Activities 411
Overall Conclusions and Recommendations 412
References 416

**Chapter 13**: The State of Coral Reef Ecosystems of the Federated States of Micronesia **419**
*Andy George, Marston Luckymis, Steve Palik, Katrina Adams, Eugene Joseph, Dave Mathias, Scotty Malakai, Mary Rose Nakayama, Curtis Graham, Kerat Rikim, Allan Marcus, Julita Albert, Vanessa Fread, Mike Hasurmai, Christina Fillmed, Willy Kostka, Alissa Takesy, Trina Leberer and Shauna Slingsby*

Environmental and Anthropogenic Stressors 421
Coral Reef Ecosystem Data-Gathering Activities and Resource Condition 425
Current Conservation Management Activities 430
Overall Conclusions and Recommendations 434
References 435

**Chapter 14**: The State of Coral Reef Ecosystems of the Commonwealth of the Northern Mariana Islands **437**
*John Starmer, Jacob Asher, Fran Castro, Deborah Gochfeld, Jamison Gove, Amy Hall, Peter Houk, Elizabeth Keenan, Joyce Miller, Robert Moffit, Marc Nadon, Robert Schroeder, Ellen Smith, Michael Trianni, Peter Vroom, Kevin Wong and Kathy Yuknavage*

Environmental and Anthropogenic Stressors 439
Coral Reef Ecosystem Data-Gathering Activities and Resource Condition 445
Water Quality and Oceanographic Conditions 446
Benthic Habitats 449
Associated Biological Communities 456
Current Conservation Management Activities 460
Overall Conclusions and Recommendations 461
References 462

**Chapter 15**: The State of Coral Reef Ecosystems of Guam **465**
*David Burdick, Valerie Brown, Jacob Asher, Mike Gawel, Lee Goldman, Amy Hall, Jean Kenyon, Trina Leberer, Emily Lundblad, Jenny McIlwain, Joyce Miller, Dwayne Minton, Marc Nadon, Nick Pioppi, Laurie Raymundo, Benjamin Richards, Robert Schroeder, Peter Schupp, Ellen Smith and Brian Zgliczynski*

Environmental and Anthropogenic Stressors 468
Coral Reef Ecosystem Data-Gathering Activities and Resource Condition 477
Water Quality and Oceanographic Conditions 480
Benthic Habitats 481
Associated Biological Communities 487
Current Conservation Management Activities 498
Overall Conclusions and Recommendations 503
References 505

**Chapter 16**: The State of Coral Reef Ecosystems of the Republic of Palau **511**
*Sebastian Marino, Andrew Bauman, Joel Miles, Ann Kitalong, Asap Bukurou, Charlene Mersai, Eric Verheij, Ilebrang Olkeriil, Kliu Basilius, Patrick Colin, Sharon Patris, Steven Victor, Wayne Andrew, Joel Miles and Yimnang Golbuu*

Environmental and Anthropogenic Stressors 513
Coral Reef Ecosystem Data-Gathering Activities and Resource Condition 526
Water Quality and Oceanographic Conditions 527
Benthic Habitats 529
Associated Biological Communities 532
Current Conservation Management Activities 532
Overall Conclusions and Recommendations 537
References 538

**Chapter 17**: National Summary **541**

**Appendix A**: National Summary Questionnaire and Instructions **549**

**Appendix B**: National Summary Questionnaire Responses by Jurisdiction **553**

## ABOUT THIS DOCUMENT

This report is the third in an ongoing series of assessments of the condition of coral reef ecosystems in the United States and Pacific Freely Associated states, and the second report to focus specifically on summarizing the results of coral reef ecosystem monitoring activities carried out by federal, state, territorial, commonwealth, private, academic, and non-governmental partners (Figure A). The chapter authors, who are scientists and managers directly involved in local efforts to conserve and monitor coral reef ecosystems, present data describing the status of water quality, benthic habitats, and the coral reef-associated biological communities and evaluate the impacts of thirteen major threats to coral reefs identified in the *National Coral Reef Action Strategy* (NOAA, 2002). The authors then briefly summarize the current conservation management activities being implemented in the 15 jurisdictions and provide conclusions and recommendations for future action. This edition of the report also contains a chapter describing some of the many National Level Activities that contribute to coral reef conservation and a National Summary chapter that is based on a questionnaire completed by the local report coordinators and/or writing team members.

Much of the work presented in this document has been funded by NOAA's Coral Reef Conservation Program (CRCP). More information about CRCP activities is available at http://www.coralreef.noaa.gov/. CRCP support complements funding from many of the other federal, state, territorial, commonwealth, and non-governmental partners who participated in this effort. Thus this report has been made possible through the collective efforts of many organizations.

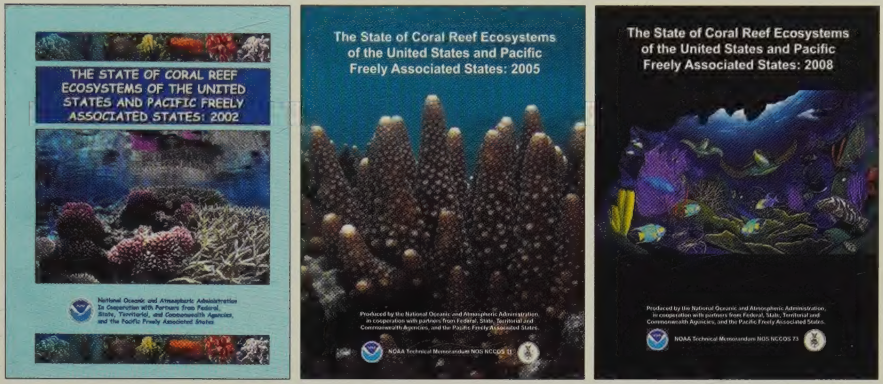

THE STATE OF CORAL REEF ECOSYSTEMS OF THE UNITED STATES AND PACIFIC FREELY ASSOCIATED STATES: 2002
The State of Coral Reef Ecosystems of the United States and Pacific Freely Associated States: 2005
The State of Coral Reef Ecosystems of the United States and Pacific Freely Associated States: 2008

*Figure A. Previous reports in this series were published in 2002 (left; Turgeon et al., 2002) and 2005 (center; Waddell, J.E., ed. 2005). The 2005 report and the 2008 report (right; Waddell and Clarke, eds. 2008) rely heavily on quantitative data from coral reef ecosystem monitoring programs.*

## INTRODUCTION

In the past decade, increased awareness regarding the declining condition of U.S. coral reefs has prompted various actions by governmental and non-governmental organizations. Presidential Executive Order 13089 created the U.S. Coral Reef Task Force (USCRTF) in 1998 to coordinate federal and state/territorial activities (Clinton, 1998), and the Coral Reef Conservation Act of 2000 provided Congressional funding for activities to conserve these important ecosystems, including mapping, monitoring and assessment projects carried out through the support of NOAA's CRCP. Numerous collaborations forged among federal agencies and state, local, non-governmental, academic and private partners now support a variety of monitoring activities. This report shares the results of many of these monitoring activities, relying heavily on quantitative, spatially-explicit data that has been collected in the recent past and comparisons with historical data where possible. The success of this effort can be attributed to the dedication of over 270 report contributors who comprised the expert writing teams in the jurisdictions and contributed to the National Level Activities and National Summary chapters. The scope and content of this report are the result of their dedication to this considerable collaborative effort.

Ultimately, the goal of this report is to answer the difficult but vital question: what is the condition of U.S. coral reef ecosystems? The report attempts to base a response on the best available science emerging from coral reef ecosystem monitoring programs in 15 jurisdictions across the country. However, few monitoring programs have been in place for longer than a decade, and many have been initiated only within the past two to five years. A few jurisdictions are just beginning to implement monitoring programs and face challenges stemming from a lack of basic habitat maps and other ecosystem data in addition to adequate training, capacity building, and technical support. There is also a general paucity of historical data describing the condition of ecosystem resources before major human impacts occurred, which limits any attempt to present the current conditions within an historical context and contributes to the phenomenon of shifting baselines (Jackson, 1997; Jackson et al., 2001; Pandolfi et al., 2005).

This report was intended to catalog existing coral reef ecosystem monitoring programs and link scientists and managers involved in coral reef conservation to additional data products, some of which have not been published before. Summarized data are presented in map, tabular and graph formats, and many of the graph figures utilize dual axes. Metadata resources for projects funded by NOAA can be accessed via the Coral Reef Information System (CoRIS; http://www.coris.noaa.gov/). Map products, imagery and other information can be obtained via Internet URLs that appear in the text and references for each chapter. The validity of all of the Internet links in the document were verified in April 2008.

## JURISDICTIONAL CHAPTERS

The scope of this report encompasses 15 jurisdictions across the U.S. and Pacific Freely Associated States. From east to west, the six Atlantic/ Caribbean/ Gulf of Mexico jurisdictions are the U.S. Virgin Islands (USVI); Puerto Rico; Navassa Island; Southeast Florida; the Florida Keys; and the Flower Garden Banks National Marine Sanctuary and other banks of the northwestern Gulf of Mexico (FGB; Figure B). In the Pacific, the nine jurisdictions are the Main Hawaiian Islands (MHI); Northwestern Hawaiian Islands (NWHI); American Samoa; Pacific Remote Island Areas (PRIA); Republic of the Marshall Islands (RMI); Federated States of Micronesia (FSM), Commonwealth of the Northern Mariana Islands (CNMI); Guam; and the Republic of Palau. Palau, FSM and RMI are former U.S. territories that gained independence but maintain compacts of free association with the U.S.; together they comprise the Freely Associated States (FAS).

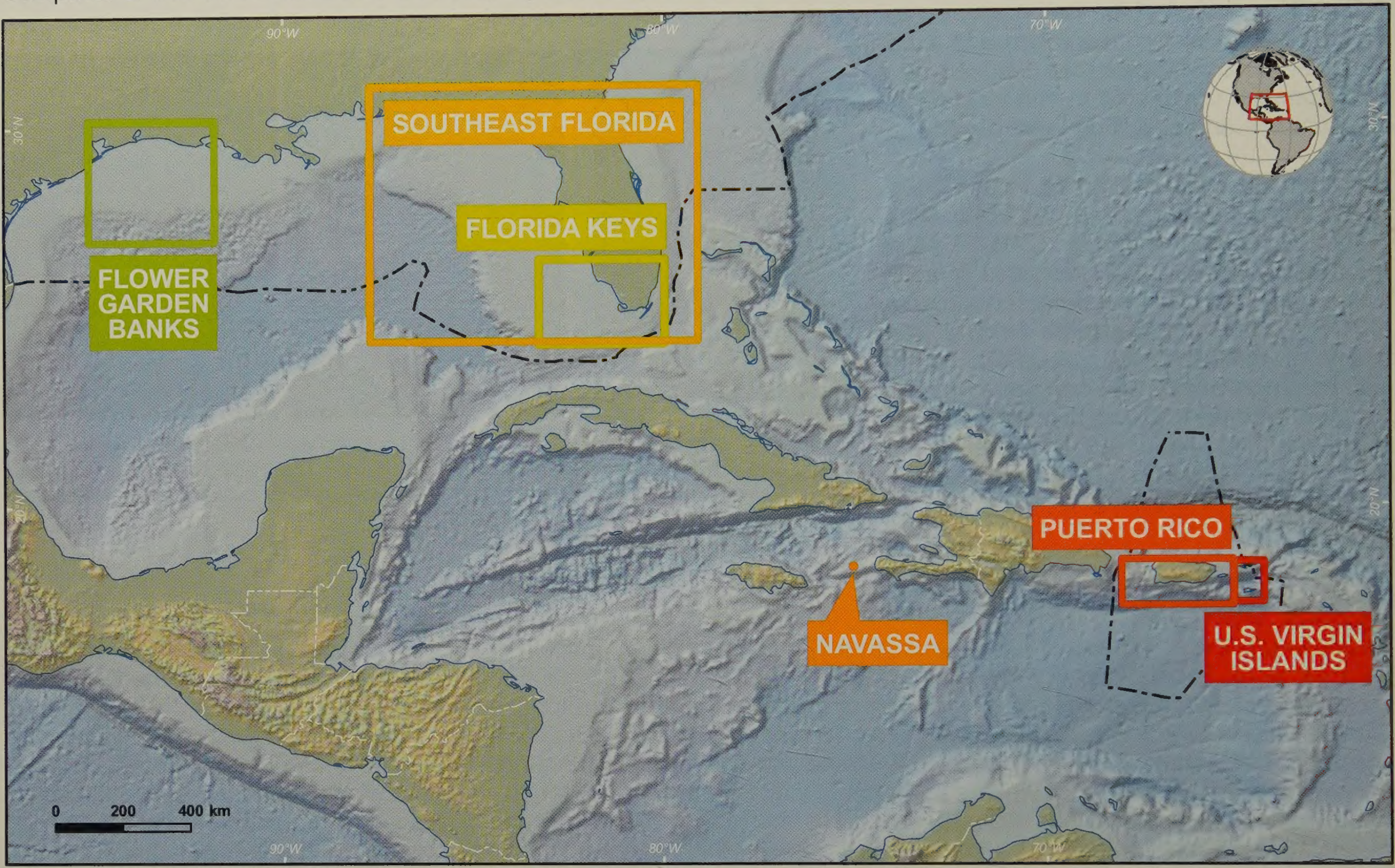


*Figure B. Six U.S. jurisdictions containing coral reefs are located in the Atlantic/ Caribbean/ Gulf of Mexico region. Map: K. Buja.*

The jurisdictions are based on political boundaries and vary in size from Navassa, with an area of 3 km$^2$, to southern Florida, which includes part of the west Florida shelf and encompasses 30,801 km$^2$ of shallow water habitats (both figures represent the estimated marine area encompassed by the 10-fathom (18 m) depth contour; Rohmann et al., 2005). Each of the 15 jurisdictions contains a unique mosaic of habitats and marine species, and these differences fundamentally affect the way monitoring is conducted as well as the analytical results obtained.

Ten of the 15 jurisdictions included in this report receive annual support from CRCP under the National Coral Reef Ecosystem Monitoring Program (NCREMP), which provides funding to local jurisdictional agencies to enable them to conduct long-term coral reef ecosystem monitoring activities. Navassa Island, the Florida Keys, FGB, NWHI, and the PRIA have not received funding through NCREMP to date. RMI and FSM have only recently joined the program and are conducting initial characterization work that will support the design and implementation of comprehensive monitoring programs.

To develop the chapters in this report, each jurisdiction was asked to designate a report coordinator who led the writing team in their efforts, edited contributions and served as a primary point of contact for the report's primary editors. Each writing team was provided with a basic chapter outline and a length limit, but the contents of each chapter were largely left to the writing team's discretion. As in the 2005 report, jurisdictional chapters were structured to: 1) describe how each of the primary threats identified in the National Coral Reef Action Strategy (NCRAS) has manifested in the jurisdiction; 2) introduce ongoing monitoring and assessment activities relative to three major categories of inquiry—water quality, benthic habitats, and associated biological communities—and provide summary results in a data-rich format; 3) highlight recent management activities that promote conservation of coral reef ecosystems; and 4) provide conclusions and recommendations for future action.

The resulting chapters contain information about coral reef ecosystem resources relative to a variety of subjects and monitoring activities that have been undertaken to document their condition. A few highlights from each region are provided below along with results from the National Summary chapter. In general, results from the chapters and the National Summary indicate that coral reef condition is declining in many locations while threats to them are increasing. Coral reef ecosystems in the U.S. and FAS continue to be beset by a number of serious threats stemming from natural and anthropogenic factors, which stress and degrade the living marine resources inhabiting coral reef ecosystems in addition to the corals themselves.

### Results from Atlantic/ Caribbean/ Gulf of Mexico Jurisdiction Chapters

The summer and fall of 2005 was one of the most active hurricane seasons recorded in the region. At the Flower Garden Banks, 192 km (120 mi) from the coast of Texas, passage of Hurricanes Katrina and Rita toppled coral colonies, leveled thickets of branching corals, and scoured channels in habitats deeper than 17 m (55 ft). In southern Florida, Hurricanes Dennis, Katrina, Rita, Ernesto, and especially Wilma caused extensive physical damage to reefs and associated ecosystems and caused the loss of approximately 300,000 lobster traps (Clark, 2006). Ironically, these storms are also credited with churning up the water column and bringing cooler waters to the surface, which reduced sea surface temperatures and buffered the effect of the massive regional coral bleaching event that affected virtually the entire Caribbean basin in the late summer and fall of 2005. Including mortality associated with the coral disease epidemic that followed the bleaching event, coral scientists in USVI and Puerto Rico recorded on average a 50% decline in live coral cover and in places up to 90% mortality of coral colonies at monitoring sites (Miller et al., 2006; García-Sais et al., 2006; Woody et al., 2008).

Few reefs in the U.S. Caribbean and Atlantic currently have a percentage of mean live hard coral cover greater than 10%, but they were once structurally complex reefs dominated by vast stands of branching corals in the genus *Acropora*. In 2005, NOAA's National Marine Fisheries Service released the Atlantic *Acropora* Status Review, which showed data collected since the 1970s indicating that acroporid corals had experienced population declines of ≥ 90% at sites across the region (Atlantic *Acropora* Review Team, 2005). Further work determined that the fates of these important reef-building species were severe enough to warrant a 'threatened' listing under the U.S. Endangered Species Act, which occurred in 2006. Protections for two species, *Acropora palmata* and *A. cervicornis*, under the act are being formulated and may affect future federal, state, territorial, commonwealth and local activities in the region.

Monitoring of Navassa Island's coral reef ecosystems indicated that a significant coral disease event occurred in 2004 following the passage of Hurricanes Charlie and Ivan. Overall hard coral cover declined in Navassa between 2002 and 2006, and in 2006, none of the sites sampled as part of two monitoring studies had a percent live coral cover > 10%. In the Florida Keys, data collected at 43 sites throughout the Florida Keys National Marine Sanctuary (FKNMS) by the Fish and Wildlife Research Institute indicate that both percent live coral cover and coral species richness declined between 1996 and 2006 in all habitat types surveyed, with the greatest declines recorded in deep, offshore reefs (CREMP, unpub. data). Until recently, many believed that coral reefs in deeper waters were less subject to anthropogenic threats than shallow-water reefs near shore, and that deeper reefs would serve as refugia for stressed coral species (Menza et al., 2007). In Broward County, Florida, four years of monitoring data revealed little change in coral species richness; percent live stony coral cover in southeast Florida generally ranges from 0.5% to 2.5% (SECREMP, unpub. data; Gilliam, 2007). Sedimentation of nearshore reefs in the USVI is nearly 50 times greater than at reefs offshore (Blondeau, unpub. data).

Populations of harvested reef fishes in Florida and the U.S. Caribbean are largely depleted. Only 3% of snappers and groupers observed on 2,401 transects in the USVI (St. John and St. Croix) surveyed by NOAA between 2001 and 2007 were equal to or longer than 35 cm (Pittman et al., in press; http://www8.nos.noaa.gov/biogeo_public/query_main.aspx). Only 2 of the 242 groupers seen during four years of surveys (n=667) in Broward County, Florida were larger than the minimum legal size (Ferro et al., 2005). In the Florida Keys, 25 of 34 species in the commercially-important snapper-grouper complex for which sufficient data were available were considered 'overfished' according to federal standards (Ault et al., 2005). The number of recreational fishers in southeast Florida increased between 1996 and 2006, as evidenced by the 41,000 additional recreational vessels registered in this period and the 25% increase in the purchases of saltwater fishing licenses (FWC, unpub. data; McDevitt, pers. comm.). By 2000, recreational fishing accounted for over 75% of total finfish landings. At Navassa Island, reef fish biomass declined between 2002 and 2006, particularly among piscivores, herbivores, and planktivores (Miller et al., 2007; McClellan et al., unpub. data). Mean sizes of fish decreased for several important fish families as well, which is thought to be largely a result of unregulated fishing by migrant Haitian artisinal fishers who travel over 30 miles in small open boats to fish at Navassa (Miller et al., 2004). A sociocultural characterization of the Haitian fishing communities was recently completed to illuminate fishing patterns and motivations behind such usage (Wiener, 2005; Miller et al., 2007).

In July 2006, the USVI government banned gill net fishing, a technique that indiscriminately catches fish of all types and size, invertebrates, turtles and birds and was virtually never used in the USVI before the 1990s. Protection of several important fish spawning aggregation (SPAG) sites through the establishment of Marine Conservation Districts (MCD) covering 45 km$^2$ of USVI federal waters has helped increase the abundance and size of some commercially important snappers and groupers in nearby St. Thomas, but large snappers and groupers are rarely observed in St. Croix (Toller, 2002). The Caribbean Fishery Management Council, which implemented an emergency closure of one SPAG in 2004 after the yellowfin grouper aggregation there was heavily exploited, continues to support mapping and monitoring efforts at MCD sites in the U.S. Caribbean. Meanwhile, in the Dry Tortugas region of the Florida Keys, state and federal agencies established a no-take Research Natural Area in early 2007 within Dry Tortugas National Park. This action increases the extent of no-take areas in the FKNMS and complements the nearby Tortugas Ecological Reserve, which was established in 2001.

### *Results from Pacific Jurisdiction Chapters*

In the Pacific region, nine chapters of this report document the impact of threats and condition of coral reef ecosystems (Figure C). Pacific coral reef ecosystems appear to be less affected by threats and are generally in better condition than reef ecosystems in the Atlantic/ Caribbean/ Gulf of Mexico region. Many of the Pacific jurisdictions extend over large areas of ocean, encompassing islands and reefs that are either too remote or too inhospitable to support human settlements. As a result, coral reef ecosystems are in relatively good condition in several Pacific jurisdictions, in particular the NWHI, PRIA, RMI, FSM and Palau, where live coral cover can exceed 70%.

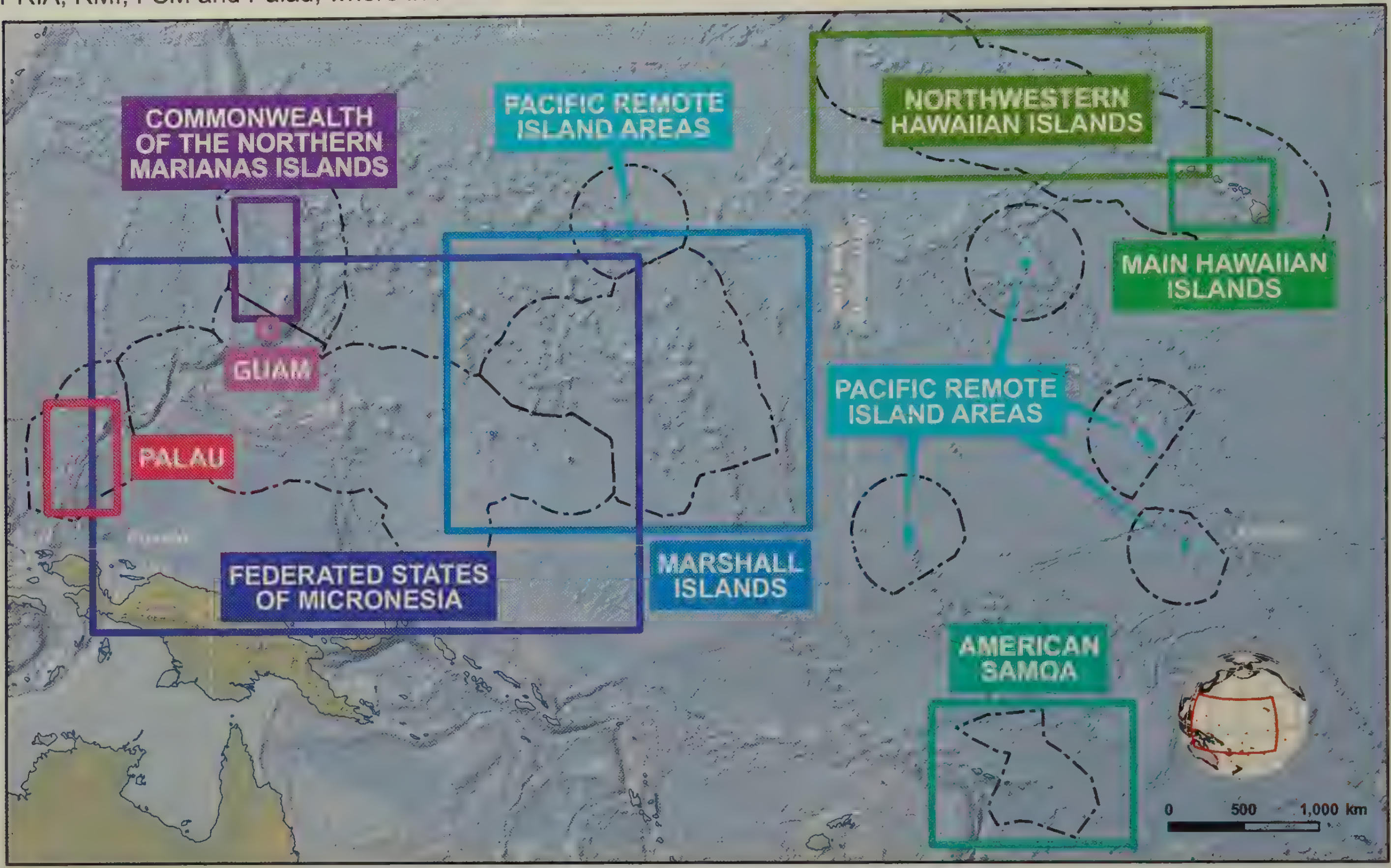

COMMONWEALTH OF THE NORTHERN MARIANAS ISLANDS
PACIFIC REMOTE ISLAND AREAS
NORTHWESTERN HAWAIIAN ISLANDS
MAIN HAWAIIAN ISLANDS
GUAM
PALAU
PACIFIC REMOTE ISLAND AREAS
FEDERATED STATES OF MICRONESIA
MARSHALL ISLANDS
AMERICAN SAMOA
0
500
1,000 km

*Figure C. Six U.S. jurisdictions containing coral reefs and the three Pacific Freely Associated States (the Republic of the Marshall Islands, the Federated States of Micronesia, and the Republic of Palau) are located in the Pacific region. Map: K. Buja.*

Water quality across the region was generally good to excellent, except in localized areas with reduced flushing such as harbors and semi-enclosed bays. Sewage and stormwater runoff events affected nearshore water quality in Oahu in 2006 and resulted in beach closures and posting of raw sewage advisories along 15.19 mi of beaches (HIDOH, 2007); brown water advisories that warn the public of the danger of stormwater discharges to Hawaii's coastal waters affected nearly 300 total beach miles in 2006 (HIDOH, 2007). Of the 83 water quality monitoring sites surveyed in Saipan, Tinian and Rota (CNMI) in 2006, over 37% were classified as impaired due to excess nutrient and bacteria levels (Houk, 2006). Unfortunately, funding for the CNMI nonpoint source pollution control program was eliminated in 2007. Data from populated areas of the RMI indicate that coral reefs near sewage outfalls and dump sites are prone to overgrowth by a black encrusting algae that can cover 30% of the substrate (D. Jacobson, pers. obs). More data about the oceanographic conditions and environmental variables that influence species distributions is available for U.S. Pacific Islands.

As in the Caribbean, coral reefs adjacent to heavily populated islands are often subject to more intense effects of stressors such as pollution, sedimentation, fishing, tourism, recreational use, and marine debris. Despite this, data from 1,682 independent transects conducted at hardbottom sites by four local monitoring programs across the MHI reported average live coral cover of 19.9%. A 2007 taxonomic expedition to French Frigate Shoals (NWHI) by the Census of Marine Life documented a number of previously unreported coral species and the possible discovery of several reef species that may be new to science. Additional range extensions and new species were observed as part of monitoring activities in the PRIA, RMI, FSM, and American Samoa. Surveys of remote atolls in the RMI documented some areas with live coral cover of 78.5%. Coral recruitment, however, has fallen to very low levels in parts of the Pacific, suggesting a decrease in the ability of corals to recover from disturbance and replenish existing populations through sexual reproduction.

Corals living in shallow back reef pools in American Samoa have begun to bleach annually, but with little resulting mortality. The corals' apparent resistance to bleaching is being investigated. Sedimentation studies in Palau, American Samoa, CNMI, and Guam document inputs and track impacts of sediment pulses on nearby reefs. In American Samoa, sites near river mouths averaged about 60 times more sediment than sites near points. In Guam and CNMI, corals suffered disturbances from crown-of-thorns sea stars, which eat live corals, and bleaching events, particularly in early fall of 2006 and 2007. Data from local long-term monitoring sites in CNMI indicate significant reductions in the cover of live coral and coralline algae and concomitant increases in the cover of turf algae (CNMI MMT, unpub. data). Coral disease increased between 2002 and 2005 in CNMI and was found to be more abundant at sites with high levels of scuba diving activity (Gochfeld, pers. obs). Studies of disease prevalence on Guam recorded values > 10% at three of 10 reefs surveyed for disease. Sedimentation is a major factor influencing the condition of nearshore habitats in Guam and is exacerbated by erosion caused by wildfires that are intentionally set by hunters.

Reef fish populations in the NWHI continue to be dominated by medium (> 25 cm) and large (> 50 cm) fish, and are similar to fish communities in many of the PRIA and remote parts of CNMI. However, comparable regional monitoring data indicate that reef fish populations adjacent to populated areas such as the main Hawaiian Islands, Guam, and parts of CNMI and American Samoa tend to have lower total fish biomass and smaller fish than sparsely-inhabited or uninhabited areas (PIFSC-CRED, unpub. data). Information on recreational landings is scarce since catch reports are not required in many Pacific jurisdictions, but recreational fishing is believed to be quite high based on creel surveys, market surveys, and other interviews of residents and fishers. In 2007, the Governor of American Samoa announced protection from fishing for 10 species of sharks and large fish, all of which had become sufficiently rare to prompt such an action. Large numbers of shark fins, allegedly harvested as tuna bycatch, continue to be exported from the Marshall Islands, which likely contributes to the decrease in shark observations in areas where they had previously been abundant. Populations of bumphead parrotfish and Napoleon wrasse, which are both targets of the live food fish trade, have declined in many places but are still present in a few remote parts of the PRIA, RMI, and FSM.

Aquatic invasive species have become major management challenges, particularly for islands that are shipping industry hubs. In the main Hawaiian Islands, where at least 287 non-native or cryptogenic species have been intentionally or unintentionally introduced, concerted efforts made by state agencies and local NGOs to remove invasive algae have met with limited long-term success but have raised public awareness of the problem. The NWHI contains far fewer introduced species, and efforts there are focused on preventing the spread of existing species and the establishment of additional non-native species. Crown-of-thorns sea stars (*Acanthaster planci*) are present in all nine Pacific jurisdictions in varying densities, and significant damage to coral communities has been documented in locations that experience periodic population increases.

NOAA's Abandoned Vessel Inventory lists over 130 abandoned vessels in Guam and 42 in the CNMI and has prioritized them for removal based on ecological and navigational considerations. Efforts to remove several of these rusting vessels and their associated debris have been undertaken in American Samoa (9 vessels) and CNMI (3 vessels) in the past few years; other removals are planned. A ship carrying 300,000 tons of cement grounded on a reef near Oahu in 2005.

Major conservation actions that have been taken in the past few years are likely to help protect some coral reef ecosystem resources in the Pacific region. For example, June 2006 marked the establishment of the Papahanaumokuakea Marine National Monument, which protects more than 140,000 $mi^2$ (362,600 $km^2$) in the central north Pacific surrounding the NWHI. Studies of marine protected areas in the MHI, Guam, and CNMI continue to demonstrate the value of MPAs in protecting fish biomass; in studies of pairs of protected and unprotected sties in the MHI, protected areas were found to contain up to eight times the biomass of unprotected areas (Friedlander et al., 2007).

In the Pacific Freely Associated States, the events of the past three years indicate an increase in momentum for building local management capacity and developing comprehensive coral reef monitoring programs. Additional monitoring activities and the data they yield will help support the development and implementation of the Micronesia Challenge. Approved by chief executives from Guam, CNMI, FSM, RMI, and Palau, the challenge sets ambitious conservation goals by calling for effective conservation of 30% of nearshore marine resources and 20% of terrestrial resources across Micronesia by 2020. Reef monitoring experts in Palau are helping train local agency personnel and provide technical assistance to the RMI and FSM. The expansion of grant funding available for monitoring in Micronesia provided through NOAA's National Coral Reef Ecosystem Monitoring Program will augment the initial characterization and monitoring efforts conducted to date, largely through the support of NGO partners and private foundations.

In Kosrae (FSM), a recent study of fish markets revealed that 70% of the fish for sale are immature and thus have never reproduced. Monitoring activities related to fish spawning aggregations, MPAs, and benthic community composition in Pohnpei are beginning to produce results, and a sedimentation study is documenting terrestrial inputs to nearshore systems which have increased due to changes in agricultural land use patterns in upland watersheds. Surveys in Kosrae in 2006 suggested that some economically and ecologically important species of fish that were recorded in 1986 surveys were no longer present. In Yap (FSM), where all reefs are privately owned within a complex system of marine tenure, recent ecological assessments are providing data that can be used in conjunction with traditional ecological knowledge to support management practices implemented by Yap's council of chiefs, government agencies, and local landowners.

In Palau, the completion of the compact road encircling the island of Babeldaob has encouraged many Palauans to return to Babeldaob and begin clearing forests, developing private land and constructing access roads, often without necessary permits or protective measures. These actions have resulted in increased sedimentation and smothering of nearshore reefs. Elsewhere in Palau, data from reef monitoring sites suggest that between 2002-2005 coral cover increased at shallow (3 m) reefs and increased even more at deeper (10 m) reefs, with an overall increase of 2.9% at long-term sites. Fish abundance also increased over this period, particularly at exposed sites on the western barrier reef.

## NATIONAL SUMMARY

Because no standard monitoring methods are used throughout all fifteen jurisdictions, data values could not be compared across jurisdictions in a National Summary format. Only data collection efforts that employ consistent methods across multiple jurisdictions at similar spatial and temporal scales will allow for the comparison of actual data values.

Instead, the contents of the National Summary chapter of this report are based on the knowledge and opinions of coastal managers and scientists who are responsible for monitoring and managing coral reef ecosystems in each jurisdiction. Opinions were collected using a survey that was completed by each chapter's report coordinator and/or writing team. The survey consisted of a multiple-choice questionnaire that allowed respondents to choose from a set of responses to evaluate the present condition, short-term trend, long-term trend and ability to monitor four key resources and ten threats (Table A). The four key resources were chosen for inclusion based on their relevance to overall ecosystem health. The ten threats were selected based on their importance and relevance across all jurisdictions. Together these 14 metrics offer a robust, standardized data set to compare coral reef ecosystem condition and trends. The questionnaire also included two questions about conservation management capacity and benthic habitat mapping in order to provide an initial self-evaluation of the ability of jurisdictions to implement conservation actions and use the available mapping products for research and conservation purposes.

*Table A. Four key resources and ten threats evaluated in the National Summary chapter.*

| **Key Resources** |
|---|
| • Water Quality |
| • Living Coral Cover |
| • Reef Fish Populations |
| • Harvested Reef Fish and Macroinvertebrates |
| **Commonly Addressed Threats** |
| • Climate Change and Coral Bleaching |
| • Coral Disease |
| • Tropical Storms |
| • Coastal Development |
| • Tourism and Recreation |
| • Commercial Fishing |
| • Subsistence and Recreational Fishing |
| • Vessel Damage |
| • Marine Debris |
| • Aquatic Invasive Species |

The results of the survey corroborate the data and information included in jurisdictional chapters and reveal that:

- The majority of key resources in the Caribbean/Atlantic/Gulf of Mexico region were reported to be in poor or fair condition. Only 6 of the 24 responses (25%) reported conditions were good (4) or excellent (2).
- Of the six jurisdictions in the Caribbean/Atlantic/Gulf of Mexico region, the most remote jurisdiction, the Flower Garden Banks, had the fewest high threats (1), and all four key resources were reported to be in good or excellent condition.
- In the Pacific, the majority (69%) of key resources (for which condition was known) were reported to be in good (16) or excellent (8) condition.
- Harvested reef fish and macroinvertebrates was the only key resource to be classified by the majority of Pacific jurisdictions as fair and the only key resource to be reported in poor condition (MHI).
- In terms of ability to monitor all threats and key resources, 17% of the responses indicated a poor ability to monitor, 49% were fair, 30% were good, and only 3% reported an excellent ability to monitor threats and/or key resources.
- Living coral cover was the only key resource for which monitoring ability was reported to be good (9) or excellent (1) by a majority of the jurisdictions. The ability to monitor three of the key threats, commercial fishing, subsistence and recreational fishing, and aquatic invasive species, was considered to be poor by nearly half of the jurisdictions.
- The average condition of most key resources declined over both the short- and long-term. More jurisdictions reported a declining trend in key resources over 10-25 years than over the past 3 years. Overall trends indicate that resource condition is declining and threats are increasing.
- For short-term trends in the condition of threats, overall results indicate that all threats but one increased over the past 3 years; 12 of 15 jurisdictions reported that tropical storms remained about the same. All threats but one also increased over the 10-25 year trend; the overall trend in the threat of commercial fishing was reported to be about the same over time based on the distribution of responses of increasing (5), about the same (5), decreasing (3) and unknown (2).
- Over the 10-25 year time period, threats for which more than 2/3 of jurisdictions reported increasing trends were climate change and coral bleaching, coral disease, tourism and recreation, subsistence and recreational fishing, and marine debris.
- Trends in threat levels over the past 3 years were reported as unknown in 8 of the responses. Fifteen responses indicated the trend of a threat was unknown over the past 10-25 years.

Although there are several important caveats regarding interpretation of these results (please see the National Summary chapter) the questionnaire provided an opportunity to focus attention on places, resources, threats and monitoring capacity that are in need of additional support. Consequently a low score in any category should be interpreted not as a failure of management, but as an indication that more concerted attention and care may be required to protect coral reef ecosystems in that location.

## NATIONAL LEVEL ACTIVITIES

This edition of the report includes a short chapter summarizing some of the activities underway at regional and national levels to support coral reef conservation. While some of these are mentioned in one or more of the jurisdictional chapters, many topics are not covered elsewhere in the report. Topics in the National Activities chapter include the Coral Reef Ecosystem Integrated Observing System (higher level integration of results of coral reef mapping and monitoring activities by NOAA and jurisdictional partners); the 2005 Caribbean region-wide bleaching event; the Endangered Species Act listing of two coral species in 2006; a review of the status of important social science projects that document motivations, values, and perceptions related to human use patterns in and economic value of coral reef ecosystems; the use of marine protected areas as a management tool for conserving coral reefs; regional implementation of the Micronesia Challenge; federal fishery management in coral reef ecosystems; changes to the Coral Reef Conservation Act of 2000 that have been proposed during the ongoing reauthorization process; the 10th anniversary of the creation of the U.S. Coral Reef Task Force; and the various activities that are planned for the International Year of the Reef in 2008.

## CONCLUSIONS

Since publication of the last report in 2005, news reports have documented several major events with negative consequences for coral reefs. As the 2005 report was being prepared for printing, a massive tsunami in Asia aptly illustrated the value of coral reefs in protecting coastal areas. Scientists surveying the tsunami damage noted a striking fact: where reefs were in good condition and structurally intact, adjacent coastal areas were spared from the full force of the waves. Where reefs had deteriorated from dredging, blast fishing and other destructive activities, there was little reef left to break the waves' momentum, which hit nearby coasts with unabated force. Later that year, the media tracked the paths of a record-breaking number of powerful hurricanes that damaged coastal areas across the Caribbean, Florida and Gulf of Mexico.

The past three years have also seen a rise in concern about the affects of climate change on the planet including ocean and coastal areas. In addition to long-standing concerns about sea level rise, increases in sea surface temperatures, and mass coral bleaching and disease epidemics, recent evidence has emerged to focus attention on predicted changes to ocean chemistry that would likely affect future coral growth. Corals and other important reef-building organisms are able to calcify their skeletal structures from sea water because of particular chemical properties. Continued increases in $CO_2$ may result in acidification of waters to the point that calcification by marine organisms can no longer occur, which would prevent future coral reef growth altogether.

Since the last reporting effort, more information has also become available to characterize the extent and distribution of nearshore sea floor habitats. Between 2005 and 2007, digital benthic habitat maps in formats compatible with Geographic Information Systems (GIS) were released for CNMI, Guam, American Samoa, the Republic of Palau and the main Hawaiian Islands. These habitat maps, along with similar products for USVI and Puerto Rico, provide baseline information on the extent and distribution of habitat types found in the seascape and are invaluable in structuring monitoring and research efforts and supporting management. Because all of the component imagery and data used to create the maps are provided to users, the initial maps produced by NOAA were able to be refined in key locations to depict habitats in greater detail for management applications. In Florida, where shallow water habitats (<18 m) are estimated to cover a vast area and numerous mapping programs are in progress, important initial steps have been taken to develop maps for targeted priority areas not previously surveyed in detail.

In water depths of 20-1,000 m, bathymetric surveys using high-resolution multibeam sonar are nearly complete for CNMI, Guam, American Samoa, the Pacific Remote Island Areas (PRIA), and the main Hawaiian Islands, and partially complete in the NWHI. A suite of additional products that are derived from multibeam sonar data are also now available. Bathymetric data collection in the Atlantic/ Caribbean/ Gulf of Mexico is proceeding more slowly and focuses survey effort on priority areas such as fishery closures, deep reef habitats, unique seafloor features, National Marine Sanctuaries, and other targeted areas. Analogous data have been collected in parts of the USVI and Puerto Rico as well. The availability of habitat maps and high-resolution bathymetric data represents major progress toward mapping goals established by the U.S. Coral Reef Task Force at its inception in 2000 (USCRTF, 2000) and provide a fundamental spatial structure that supports management, monitoring and research objectives.

Efforts are underway in several jurisdictions to nominate and designate coral reef ecosystems as World Heritage natural sites under UNESCO. Locations such as Bikini, Likiep, Mili and other atolls in the northern Marshall Islands, Palau's Rock Islands, Papahanaumokuakea Marine National Monument (NWHI) and And Atoll (FSM) have been proposed or nominated as sites that may join the immense Phoenix Islands Protected Area of Kiribati on the list of natural sites in the tropical Pacific considered important to the global community for their exceptional natural beauty, importance to biological and ecological processes, and conservation of the earth's biological diversity (http://whc.unesco.org/en/criteria/).

For all the pressures presently stressing reefs adjacent to populated coastlines, vast areas of reefs in relatively good condition persist in remote parts of the Pacific. A recent research expedition to the Line and Phoenix Islands (including the PRIA) led by the Scripps Institute of Oceanography documented a correlation between level of human influence and reef health metrics, but found that even remote areas are not immune to threats. By the time the Pacific Islands Fishery Science Center's Coral Reef Ecosystem Division returned from their biennial cruise to American Samoa and the PRIA in April 2008, preliminary data analysis suggested that large (> 50 cm) fish biomass at Rose Atoll National Wildlife Refuge (American Samoa) in 2008 had dropped to 20% of 2002 levels, likely due to poaching at this remote protected atoll (R. Brainard, pers. comm.). Other recent surveys in remote areas of the Marshall Islands and FSM also noted a virtual absence of large, long-lived species coveted in the live food fish trade where once they were abundant. These findings emphasize the need for new technology to enable effective surveillance and enforcement of fisheries regulations regardless of the location's proximity to major human settlements.

As the global population continues to increase and demographic shifts toward coastal areas persist, even greater pressures will be placed on nearshore resources to satisfy human desires for food, culture, tourism, recreation and profit. Key issues related to usage and access to coral reef ecosystem resources are likely to intensify as conflicts over incompatible uses become more frequent. Looking ahead, decision makers must find a means to balance users' demands with efforts to conserve the resources that remain.

Despite the investments made to date in managing and monitoring U.S. coral reef ecosystems and increasing management capacity at all levels, coral reef ecosystem resources have continued to decline over the short- and long-term. Present monitoring efforts are inadequate to support effective management and document the impacts of key threats and resource condition with sufficient confidence to detect change at meaningful temporal and spatial scales. Further support at all levels is needed to augment our ability to understand the impacts of threats and mitigate damage that occurs. Significant actions and bold protective measures are required if reef conditions are expected to improve in the future.

## REFERENCES

Acropora Biological Review Team. 2005. Atlantic Acropora Status Review Document. Report to National Marine Fisheries Service, Southeast Regional Office. March 3, 2005. 152 p + App. http://sero.nmfs.noaa.gov/pr/pdf/050303%20status%20review.pdf.

Ault, J.S., J.A. Bohnsack, S.G. Smith, and L. Luo. 2005. Towards sustainable multispecies fisheries in the Florida, USA, coral reef ecosystem. Bull. Mar. Sci. 76: 595-622.

Blondeau, J. University of the Virgin Islands, Center for Marine and Environmental Studies. St. Thomas, USVI. Personal communication.

Brainard, R.E. NOAA Pacific Islands Fishery Science Center, Coral Reef Ecosystem Division. Honolulu, HI. Personal communication.

Caldow, C., R.D. Clark, M.E. Monaco. In press. A point for comparison: the Flower Garden Banks National Marine Sanctuary. In: Proceedings of the 60th Gulf and Caribbean Fisheries Institute, Punta Cana, Dominican Republic. November, 2007.

Clark, C. 2006. Lobster fishermen stake it all on 2006 season. Miami Herald. Miami, FL. http://www.redorbit.com/news/business/605221/lobster_fishermen_stake_it_all_on_2006_season/index.html.

Clinton, W. J. 1998. Executive Order 13089: Coral Reef Protection. The White House.

Ferro, F.M., L.K.B. Jordan, and R.M. Spieler. 2005. The Marine Fishes of Broward County, Florida: Final Report of 1998-2002 Survey Results. NOAA Technical Memorandum NMFS SEFSC 532. Miami, FL. 73 pp.

Friedlander, A.M., Brown, E.K., Monaco, M.E. 2007b. Defining Reef Fish Habitat Utilization Patterns in Hawaii: Comparisons Between Marine Protected Areas and Areas Open to Fishing. Marine Ecology Progress Series.

García-Sais, J. R., R. Castro, J. Sabater-Clavell, R. Esteves and M. Carlo. 2006. Monitoring of coral reef communities from natural reserves in Puerto Rico, 2006: Isla Desecheo, Rincon, Mayaguez Bay, Guanica, Ponce and Isla Caja de Muerto. Final Report submitted to the Department of Natural and Environmental Resources of Puerto Rico, San Juan, P. R. 151 p

Gilliam, D.S. 2007. Southeast Florida Coral Reef Evaluation and Monitoring Project 2006 Year 4 Final Report. Prepared for: Florida Fish and Wildlife Conservation Commission, Fish and Wildlife Research Institute, Florida Department of Environmental Protection. 31 pp. http://www.floridadep.org/coastal/programs/coral/reports/.

Gochfeld, Deborah. National Center for Natural Products Research, University of Mississippi. University, MS. Personal observation.

Jackson, J.B.C. 1997. Reef Since Columbus. Coral Reefs 16 (suppl.): S23-S32.

Jackson, J.B.C : Kirby, M X : Berger, W H : Bjorndal, K A : Botsford, L W : Bourque, B J : Bradbury, R H : Cooke, R : Erlandson, J : Estes, J A : Hughes, T P : Kidwell, S : Lange, C B : Lenihan, H S : Pandolfi, J M : Peterson, C H : Steneck, R S : Tegner, M J : Warner, R R. 2001. Historical overfishing and the recent collapse of coastal ecosystems. Science 293(5530): 629-37.

Menza, C., M. Kendall, C. Rogers and J. Miller. 2007. A deep reef in deep trouble. Continental Shelf Research 27: 2224-2230.

Miller, J., R. Waara, E. Muller, and C.S. Rogers. 2006. Coral bleaching and disease combine to cause extensive mortality on reefs in U.S. Virgin Islands. Coral Reefs 25(3): 418.

Miller, M.W., D.B. McClellan, J.W. Wiener, and B. Stoffle. 2007. Apparent rapid fisheries escalation at a remote Caribbean island. Environ. Conserv. 34: 92-94.

NOAA (National Oceanic and Atmospheric Administration). 2002. A National Coral Reef Action Strategy: Report to Congress on implementation of the Coral Reef Conservation Act of 2002 and the National Action Plan to Conserve Coral Reefs in 2002-2003. NOAA. Silver Spring, Maryland.

Pandolfi, J.M., Jackson, J.B.C., Baron, N., Bradbury, R.H., Guzman, H.M., Hughes, T.P., Kappel, C.V., Micheli, F., Ogden, J.C. , Possingham, H.P. and E. Sala. 2005. Are U.S. coral reefs on the slippery slope to slime?. Science 307(5716): 1725-1726.

Pittman, S.J., S.D. Hile, C.F.G. Jeffrey, C. Caldow, M.S. Kendall, M.E. Monaco, Z. Hillis-Starr. 2008. Fish assemblages and benthic habitats of the Buck Island Reef National Monument (St. Croix, U.S. Virgin Islands) and the surrounding seascape: A characterization of spatial and temporal patterns. NOAA Technical Memorandum 71. NOAA/NCCOS Center for Coastal Monitoring and Assessment's Biogeography Branch. Silver Spring, MD. 67 pp.

Toller, W. 2002. Quantitative estimates of species composition and abundance of fishes, and fish species/habitat associations in St. Croix, U.S. Virgin Islands. Final Report, F-7-17. Division of Fish and Wildlife, Department of Planning and Natural Resources, U.S. Virgin Islands. 44 pp. http://www.vifishandwildlife.com/Fisheries/FisheriesReports/2002/.

Turgeon, D.D., R.G. Asch, B.D. Causey, R.E. Dodge, W. Jaap, K. Banks, J. Delaney, B.D. Keller, R. Speiler, C.A. Matos, J.R. Garcia, E. Diaz, D. Catanzaro, C.S. Rogers, Z. Hillis-Starr, R. Nemeth, M. Taylor, G.P. Schmahl, M.W. Miller, D.A. Gulko, J.E. Maragos, A.M. Friedlander, C.L. Hunter, R.S. Brainard, P. Craig, R.H. Richond, G. Davis, J. Starmer, M. Trianni, P. Houk, C.E. Birkeland, A. Edward, Y. Golbuu, J. Gutierrez, N. Idechong, G. Paulay, A. Tafileichig, and N. Vander Velde. 2002. The State of Coral Reef Ecosystems of the United States and Pacific Freely Associated States: 2002. National Oceanic and Atmospheric Administration, National Ocean Service, National Centers for Coastal Ocean Science. Silver Spring, MD. 265 pp.

USCRTF (United States Coral Reef Task Force). 2000. The National Action Plan to Conserve Coral Reefs. USCRTF. Washington, D.C. 33 pp. + appendices.

Waddell, J.E. (ed.), 2005. The State of Coral Reef Ecosystems of the United States and Pacific Freely Associated States: 2005. NOAA Technical Memorandum NOS NCCOS 11. NOAA/NCCOS Center for Coastal Monitoring and Assessment's Biogeography Team. Silver Spring, MD. 522 pp.

Woody, K., A. Atkinson, R. Clark, C. Jeffrey, I. Lundgren, J. MIller, M.Monaco, E. Muller, M. Patterson, C. Rogers, T. Smith, T. Spitzak, R. Waara, K. Whelan, B. Witcher, and A. Wright. 2008. Coral Bleaching in the U.S. Virgin Islands in 2005 and 2006. pp. 68-72. In: Wilkinson, C. and D. Souter (eds.). Status of Caribbean coral reefs after bleaching and hurricanes in 2005. Global Coral Reef Monitoring Network and Reef and Rainforest Research Centre, Townsville, Australia. 152 pp.

# National Level Activities to Support U.S. and FAS Coral Conservation

Alicia Clarke[1], Tim Battista[1], Beth Dieveney[2], Dwight Gledhill[3], Meghan Gombos[4], Christopher Jeffrey[1], Jennifer Koss[5], Trina Leberer[6], Christy Loper[2], Gang Liu[3], Joyce Miller[7], Jennifer Moore[8], Jessica Morgan[3], Shannon Simpson[2], Jeannette Waddell[1], Dana Wusinich-Mendez[4]

In addition to the local and partnership efforts underway in each of the U.S. and FAS jurisdictions, there are several important activities conducted at the national and regional levels that contribute to coral reef ecosystem conservation across jurisdictional boundaries. These include efforts to map the distribution of and monitor the status of coral reefs that occur as part of the National Oceanic and Atmospheric Administration's (NOAA) Coral Reef Ecosystem Integrated Observing System and NOAA's Coral Reef Watch program; the 2005 Caribbean Coral Bleaching event; the recent Endangered Species Act listing of the Caribbean corals *Acropora cervicornis* and *Acropora palmata* as threatened species; a shift towards greater incorporation of social science to better understand the human dimensions of coral reef conservation; increases in the designation and implementation of Marine Protected Areas (MPAs) and the compilation of a report describing the status of U.S. MPAs in coral reef jurisdictions; the ambitious attempts by Micronesian states to protect terrestrial and marine ecosystems under the Micronesian Challenge; changes in regional fisheries regulations to better protect manage populations of harvested reef organisms; the reauthorization of the Coral Reef Conservation Act of 2000; the 10th anniversary of the U.S. Coral Reef Task Force, which serves as a coordinating body for conservation activities carried out by federal and jurisdictional partners and others; and efforts to raise public awareness and understanding about the plight of coral reef ecosystems through the designation of the International Year of the Reef in 2008. These efforts are introduced in this chapter to characterize some of the major initiatives underway at higher levels of government. The sections provide links to additional information for those who wish to learn more about national level activities that contribute to coral reef conservation.

## CORAL REEF ECOSYSTEM INTEGRATED OBSERVING SYSTEM

NOAA's Coral Reef Ecosystem Integrated Observing System (CREIOS) includes mapping and monitoring activities that provide data and information as a foundation for management activities and conservation efforts. Mapping provides a detailed picture of the physical and biological structure of coral reef communities. Monitoring also includes both biological and physical aspects: direct, periodic field observations of the condition of critical reef ecosystems, and automated, continuous monitoring of key environmental factors that are known to affect their status. CREIOS integrates its mapping and monitoring activities to accurately document the status and trends in the conditions of habitats and living marine resources, and determine the depth ranges, geomorphologic zones, and reef types present in coral reef environments. The data produced through mapping and monitoring projects are disseminated to coral reef managers and other users through a variety of NOAA websites and databases that make this information publicly available. The Coral Reef Information System (CoRIS) serves as a single portal for managing coral reef-related metadata generated through NOAA and partnership efforts.

### Coral Reef Ecosystem Mapping and Monitoring

Mapping the spatial extent and characteristics of coral reef ecosystems is an integral component of CREIOS. Mapping activities include projects that use image analysis and acoustic sensing to map coral reef ecosystems from the shoreline to a maximum depth of about 1,000 m, which includes the depth limits at which hermatypic (reef-building) corals can survive due to light availability. In shallow water areas (<30 m), NOAA has generated benthic habitat maps through visual interpretation of features that are visible in georeferenced aerial photographs, high-resolution satellite imagery and bathymetric Light Detecting and Ranging (LIDAR) data. These maps classify reef ecosystems using a hierarchical classification scheme based on geomorphological zones, underlying substrate/structure, and biological cover. Areas too deep to be clearly visible in imagery (30 to 1,000 m) are surveyed using acoustic technologies, including sidescan sonar, and single- and multibeam sensors. These sensors provide data used primarily to develop high resolution bathymetric maps of the seafloor, derived products and simplified habitat maps.

An update on the status of NOAA's coral reef ecosystem mapping activities in each jurisdiction is provided in Table 1.1. The table differentiates progress according to the NOAA Coral Reef Conservation Program's two main approaches to mapping: visual interpretation of high-resolution satellite imagery used to create shallow-water (<30 m) benthic habitat maps and the collection of multibeam bathymetric data for seafloor areas deeper than 30 m used to create topographic maps of the seafloor and other derived products. Progress is measured against goals established by the U.S. Coral Reef Task Force in the *National Action Plan to Conserve Coral Reefs* (USCRTF, 2000). By December 2007, the production of high-resolution digital benthic habitat maps for U.S. shallow-water coral reef ecosystems was complete for priority areas identified in the Plan except for portions of the Northwestern Hawaiian Islands (NWHI), Florida, the Pacific Remote Is-

---

1. NOAA National Ocean Service, Center for Costal Monitoring and Assessment, Biogeography Branch
2. NOAA Coral Reef Conservation Program
3. NOAA Coral Reef Watch
4. NOAA Office of Ocean and Coastal Resource Management
5. NOAA National Marine Fisheries Service, Office of Habitat Conservation
6. The Nature Conservancy
7. NOAA National Marine Fisheries Service, Pacific Islands Fisheries Science Center, Coral Reef Ecosystem Division
8. NOAA National Marine Fisheries Service Protected Resources Division

*Table 1.1 Status of shallow-water and moderate depth mapping of seafloor characteristics and habitats for each jurisdiction, status of progress based on product availability and the jurisdictional survey, and ability of jurisdictions to use the map products provided and apply the maps in support of research and conservation efforts. The final category was included to identify where training in how to use mapping products is needed. Sources: CCMA-BB; PIFSC-CRED.*

| JURISDICTION | BENTHIC HABITAT MAP PRODUCTS | | BATHYMETRIC PRODUCTS | | Status of Mapping Progress (quantitative) | Status of Mapping Progress (survey of jurisdictions) | APPLICATION OF MAPS |
|---|---|---|---|---|---|---|---|
| | Shallow-Water (<30 m) | Moderate depth (30-1000 m) | Shallow-Water (<30 m) | Moderate depth (30-1000 m) | | | Ability to apply map products in support of research & conservation |
| USVI | 75-100% | 0-25% | 25-50% | 25-50% | FAIR | GOOD | GOOD |
| Puerto Rico | 75-100% | 0-25% | 75-100% | 0-25% | FAIR | GOOD | GOOD |
| Navassa Island | 25-50% | 0-25% | 75-100% | 75-100% | GOOD | GOOD | FAIR |
| Southeast Florida | 75-100% | 0-25% | 0-25% | 0-25% | POOR | FAIR | GOOD |
| Florida Keys | 50-75% | 0-25% | 0-25% | 0-25% | POOR | FAIR | FAIR |
| Flower Garden Banks | N/A | 0-25% | N/A | 75-100% | GOOD | GOOD | EXCELLENT |
| Main Hawaiian Islands | 75-100% | 0-25% | 75-100% | 75-100% | GOOD | GOOD | GOOD |
| Northwestern Hawaiian Islands | 50-75% | 0-25% | 25-50% | 25-50% | FAIR | FAIR | GOOD |
| American Samoa | 75-100% | 0-25% | 25-50% | 75-100% | GOOD | EXCELLENT | GOOD |
| PRIA | 0-25% | 0-25% | 0-25% | 75-100% | POOR | EXCELLENT | GOOD |
| Marshall Islands | 0-25% | 0-25% | 0-25% | 0-25% | POOR | POOR | POOR |
| Federated States of Micronesia | 0-25% | 0-25% | 0-25% | 0-25% | POOR | POOR | POOR |
| CNMI | 75-100% | 0-25% | 50-75% | 75-100% | GOOD | GOOD | GOOD |
| Guam | 75-100% | 0-25% | 75-100% | 75-100% | GOOD | GOOD | GOOD |
| Palau | 75-100% | 0-25% | 0-25% | 0-25% | POOR | FAIR | FAIR |

lands, the Marshall Islands, and the Federated States of Micronesia (Navassa Island and the banks in the Gulf of Mexico were not part of the original scope of work). Moderate-depth bathymetric surveys are largely complete in the Pacific jurisdictions but are partially complete or incomplete in the Caribbean region, the NWHI, and the Freely Associated States. These products were designed to be used together to provide a seamless picture of marine habitats from the shoreline to 1,000 m in support of coral reef management actions.

The final three columns of the table score each jurisdiction according to the status of mapping progress based on the preceding four columns and based on a questionnaire circulated to this report's local report coordinators and writing teams. In the questionnaire, respondents were asked to characterize the availability of map products and evaluate how well the jurisdiction is "able to use the map products and tools available and apply them for research and conservation purposes." More details on the questionnaire and individual responses can be found in the National Summary chapter.

Successful conservation of coral reef ecosystems must respond to changes in environmental, economic, and social conditions over time. CREIOS examines both the biological components of coral reef ecosystems and the physical environmental conditions that influence the development and maintenance of those systems. Monitoring allows managers and others to assess coral reef conditions, diagnose problems, prioritize and implement solutions, evaluate the results of management decisions, and forecast future conditions. In and around the reef ecosystems of the U.S., NOAA uses instrumented buoys, subsurface moored instruments, satellite remote sensing, satellite-tracked drifting buoys, *in situ* oceanographic and biological observations, site-specific ecological assessments, and broad-scale towed-diver surveys conducted by an interdisciplinary team of scientists (Figure 1.1). The *in situ* biological observations of NOAA scientists are augmented by the biological observations of local scientists and managers who receive funding under the National Coral Reef Ecosystem Monitoring Program to conduct complementary monitoring programs with higher temporal frequency.

In addition to *in situ* monitoring in the Pacific and Atlantic regions, CREIOS provides global satellite monitoring of sea surface temperature (SST), thermal stress, and other parameters of the coral reef environment as described below.

CREIOS provides the long-term monitoring that enables coral reef managers to detect and act on significant natural or anthropogenic changes to these ecosystems. Integration of the long-term spatial and temporal data from surface and subsurface moorings, *in situ* observations, and satellite remote sensing provides researchers and resource managers an improved understanding of the influences of global climate changes on coral reef ecosystems.

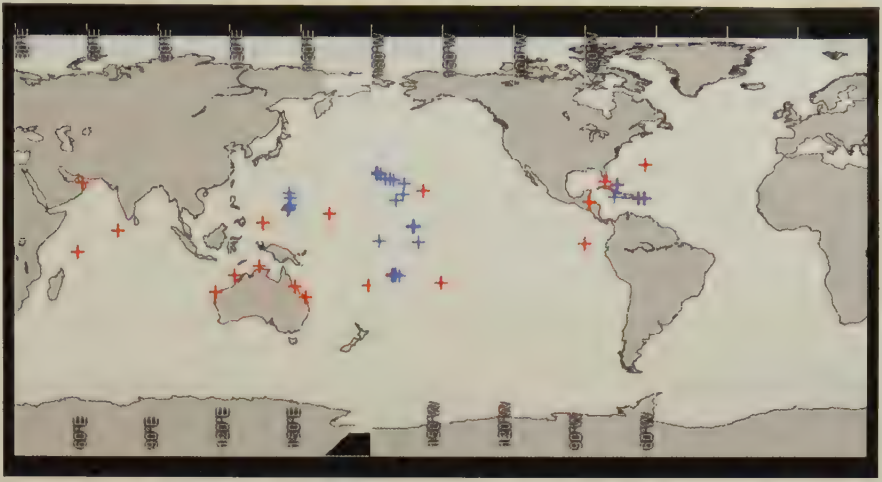


*Figure 1.1. CREIOS in situ (blue) and satellite (red) fixed monitoring stations. Source: NOAA Coral Reef Watch.*

## Ocean Acidification

The 2007 Intergovernmental Panel on Climate Change assessment reported that global temperature increased substantially over the last 100 years, due in large part to the burning of fossil fuels. Increases in ocean temperatures as a consequence of rising atmospheric carbon dioxide ($CO_2$) levels threaten coral reef ecosystems through increased frequency and severity of mass coral bleaching and disease events, sea level rise, and possibly storm activity (IPCC, 2007). In addition, increasing atmospheric $CO_2$ is already altering the chemistry of seawater in ways that are likely to reduce calcification rates in reef-building organisms (Figure 1.2). Reduction in calcification rates directly affects both the growth of individual corals and the ability of reefs to build structure at rates greater than erosional forces.

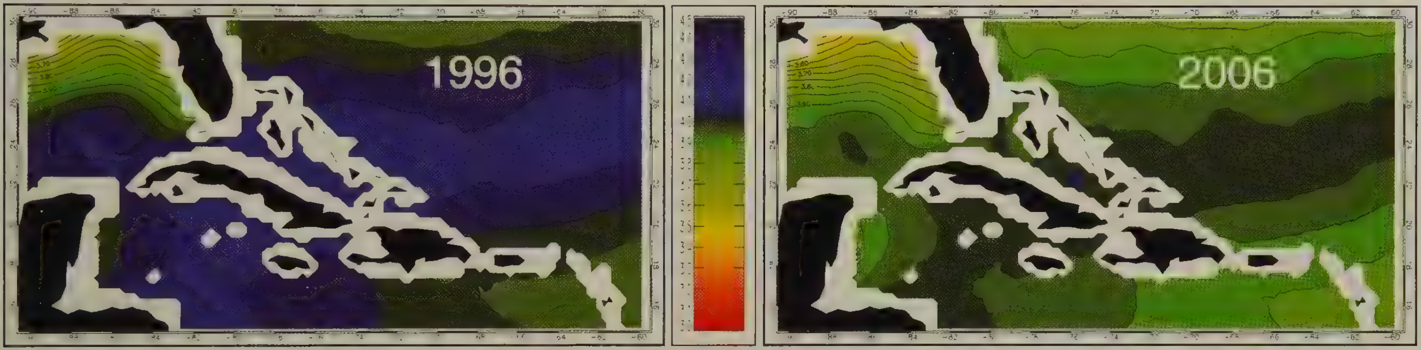


*Figure 1.2. Satellite and ship observations are coupled to model changes in surface ocean chemistry as a consequence of ocean acidification, which occurs as a direct consequence of rising atmospheric carbon dioxide and its uptake by ocean surface waters. Shown here are the annual mean aragonite saturation state values for the northern Caribbean region for 1996 (left) and 2006 (right). Aragonite saturation state imparts an important control on the rate at which coral communities build reefs, and its continued decrease may prove detrimental to reefs globally. Source: NOAA Coral Reef Watch.*

NOAA, in partnership with the National Science Foundation and the U.S. Geological Survey, released the interagency report *Impacts of Ocean Acidification on Coral Reefs and Other Marine Calcifiers: A Guide for Future Research* in 2006, which documents the threats posed by ocean acidification and highlights actions that need to be taken to better understand the consequences for marine ecosystems (http://www.ucar.edu/communications/Final_acidification.pdf). NOAA has been indirectly monitoring ocean acidification through cruises and hydrographic stations and recently began deployment of a limited number of autonomous sensors on buoys and fixed stations capable of measuring the relevant chemistry. NOAA has supported research activities that combine data from *in situ* instruments, satellites, and models to track changes in ocean chemistry and monitor the responses of reef communities. Work has begun on development of concepts for a Coral Reef Metabolic Monitoring Network, which will characterize *in situ* carbonate chemistry near selected reefs in relation to offshore sea surface chemistry as derived from satellite remote sensing. To date, this effort has three components, including: 1) a new model based on satellite data to estimate surface $pCO_2$ and other carbon chemistry parameters for the greater Caribbean region; 2) deployment of oceanic sensors at Lee Stocking Island (Bahamas), Molasses Reef (Florida Keys), and La Parguera, Puerto Rico to provide near-real-time $pCO_2$ data, and 3) a Caribbean pilot study of the new Reef Metabolic Index, which incorporates $pCO_2$ estimates from satellite data with *in situ* $pCO_2$ sensor data to monitor coral reef status in response to climate- and ocean acidification-related stress.

## Satellite Bleaching Alerts

Since 2000, NOAA has been developing and a refining a system to track thermal stress on corals and predict coral bleaching using satellite-based SST data. In 2005, NOAA Coral Reef Watch launched the Satellite Bleaching Alerts (SBA) system, which sends out automated e-mail watches and warnings when conditions are detected that may lead to coral bleaching. These mass bleaching alerts are an important component of Bleaching Response Plans and reef management planning since they alert managers to the need to deploy monitoring teams. Five alert level categories are monitored in near-real-time at 24 Virtual Station sites worldwide (Figure 1.1), based on satellite-derived SST observations and calculations of coral bleaching "HotSpots", which measure current thermal stress, and Degree Heating Weeks, which measure accumulated thermal stress over time.

*Table 1.1. Maximum annual coral bleaching Degree Heating Weeks (DHWs) at each jurisdiction from 2001-2007. Each DHW represents one week of temperatures 1°C above the maximum monthly average. DHW values are color-coded to reflect the intensity of accumulated thermal stress: Blue, DHW=0; Green, 0<DHW<4; Orange, 4≤DHW<8; Red, DHW≥8]. Coral bleaching is expected to occur at DHWs above 4 with mass bleaching and related mortality at DHWs above 8. If a thermal stress event spans two years (e.g., November-January), then the maximum DHW for each year may occur during a single event; this situation is indicated by a gray box.*

| **Jurisdiction** | **Island** | **DHW 2001** | **DHW 2002** | **DHW 2003** | **DHW 2004** | **DHW 2005** | **DHW 2006** | **DHW 2007** |
|---|---|---|---|---|---|---|---|---|
| USVI | | 0.3 | 0.7 | 3.0 | 2.6 | 14.7 | 3.6 | 1.7 |
| Puerto Rico | | 0.6 | 0.8 | 4.1 | 3.2 | 11.2 | 2.9 | 1.1 |
| Florida | | 3.5 | 1.4 | 4.2 | 4.8 | 9.2 | 2.3 | 12.2 |
| Navassa | | 1.1 | 0.0 | 4.7 | 2.2 | 10.5 | 5.1 | 2.7 |
| Flower Garden Banks | | 0.0 | 0.7 | 0.0 | 1.9 | 7.6 | 2.7 | 1.3 |
| Hawaii | Hawaii | 0.0 | 0.0 | 0.0 | 0.5 | 0.0 | 0.0 | 0.0 |
| | Oahu | 0.0 | 0.0 | 0.5 | 2.8 | 0.0 | 0.0 | 0.0 |
| | Kauai | 0.0 | 0.0 | 0.0 | 1.1 | 0.0 | 0.0 | 0.0 |
| NWHI | Nihoa | 0.0 | 0.0 | 0.0 | 0.6 | 0.0 | 0.0 | 0.0 |
| | French Frigate Shoals | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Maro Reef | 0.0 | 0.0 | 0.0 | 1.8 | 1.1 | 0.0 | 0.0 |
| | LIsianski | 0.0 | 1.7 | 0.0 | 2.2 | 0.6 | 0.0 | 0.0 |
| | Midway | 0.0 | 7.6 | 0.0 | 4.7 | 0.0 | 0.0 | 1.1 |
| | Kure | 0.5 | 8.7 | 0.0 | 1.8 | 0.5 | 0.0 | 3.1 |
| American Samoa | | 0.5 | 1.5 | 5.0 | 1.5 | 0.0 | 0.0 | 0.0 |
| PRIAs | Johnston | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Palmyra | 2.5 | 12.0 | 4.5 | 4.1 | 1.6 | 1.0 | 1.0 |
| | Kingman | 3.0 | 8.8 | 4.3 | 5.3 | 2.2 | 1.0 | 1.0 |
| | Baker | 1.6 | 18.3 | 19.7 | 12.2 | 8.5 | 16.2 | 16.8 |
| | Wake | 0.0 | 0.0 | 0.0 | 0.6 | 0.0 | 0.0 | 0.0 |
| | Jarvis | 0.5 | 24.4 | 23.0 | 5.5 | 1.1 | 4.3 | 4.3 |
| | Howland | 1.6 | 17.7 | 18.7 | 14.0 | 6.1 | 16.2 | 16.8 |
| | Rose | 0.0 | 2.3 | 6.4 | 0.5 | 3.2 | 0.0 | 0.0 |
| Marshall Islands | Majuro | 0.0 | 0.0 | 1.1 | 1.5 | 1.5 | 0.0 | 0.0 |
| | Kwajalein | 1.1 | 0.5 | 1.1 | 0.6 | 0.5 | 0.0 | 0.0 |
| | Bikini | 0.6 | 2.2 | 0.5 | 0.0 | 0.0 | 0.0 | 0.0 |
| Federated States of Micronesia | Kosrae | 0.6 | 0.6 | 4.3 | 3.3 | 1.5 | 1.5 | 0.0 |
| | Pohnpei | 4.0 | 3.4 | 1.3 | 1.3 | 0.5 | 0.0 | 0.0 |
| | Chuuk | 3.7 | 1.2 | 2.7 | 2.7 | 1.0 | 1.0 | 1.0 |
| | Yap | 2.9 | 1.7 | 1.5 | 0.5 | 0.0 | 0.0 | 0.0 |
| Guam | | 1.3 | 0.0 | 2.2 | 1.0 | 0.0 | 2.6 | 2.8 |
| CNMI | Asuncion | 8.3 | 0.6 | 4.8 | 0.0 | 0.5 | 0.0 | 3.4 |
| | Agrihan | 8.3 | 0.6 | 4.3 | 0.0 | 0.5 | 0.0 | 3.5 |
| | Pagan | 8.9 | 0.0 | 3.6 | 0.0 | 0.5 | 0.0 | 3.5 |
| | Saipan | 3.1 | 0.5 | 2.0 | 0.0 | 0.0 | 0.6 | 1.0 |
| Palau | | 2.2 | 0.6 | 0.6 | 0.0 | 0.0 | 0.0 | 0.0 |

When no thermal stress is present, the Virtual Station is under "No Stress" and no coral bleaching is expected. When HotSpots are present (0<HotSpot<1), corals are experiencing low-level thermal stress and a "Bleaching Watch" alert is in effect. As thermal stress begins to accumulate (HotSpot≥1 and 0<DHW<4), a "Bleaching Warning" alert is sent out and managers should be aware that a bleaching event may occur. At "Alert Level 1" (HotSpot≥1 and 4≤DHW<8) coral bleaching is expected. Finally, "Alert Level 2" (HotSpot≥1 and DHW≥8) indicates that significant mass coral bleaching and bleaching-related mortality are likely. The maximum annual DHWs for all U.S. and FAS jurisdictions are given in Table 1.1. Stakeholders can subscribe to the SBA system on the web at: http://coralreefwatch-satops.noaa.gov/email_alert_request.html. To date, over 250 subscribers from at least 29 nations have signed up to receive alerts via this system.

## A Reef Manager's Guide to Coral Bleaching

In 2003, USCRTF members committed to develop an interagency partnership to plan a comprehensive, integrative program for understanding local and system-wide coral reef responses to climate change, including application of this knowledge to local reef management. To support this effort, NOAA, EPA and DOI sponsored a workshop on *Coral Reefs, Climate and Coral Bleaching* with participation by over 100 scientists and managers from local and federal governments, universities, the private sector, and non-governmental organizations. As a direct result of this workshop, NOAA and the Great Barrier Reef Marine Park Authority, working with International Union for the Conservation of Nature and Natural Resources, EPA, and a variety of other domestic and international partners, developed *A Reef Manager's Guide to Coral Bleaching* (http://www.coris.noaa.gov/activities/reef_managers_guide/). The Guide articulates the state of knowledge on the causes and consequences of coral bleaching and presents management strategies to help local and regional reef managers prepare for and respond to mass coral bleaching. The Guide includes contributions from over 50 experts in coral bleaching and coral reef management from 30 organizations.

*A Reef Manager's Guide to Coral Bleaching* was released in the fall of 2006, and is available to managers as a resource for developing strategies to reduce the impacts of coral bleaching in coral reef ecosystems (Figure 1.3). The Guide provides information on responding to mass bleaching events; developing bleaching response plans; assessing ecological, social, and economic impacts; and using tools to identify and build long-term reef resilience.

Following the publication of *A Reef Manager's Guide to Coral Bleaching*, the NOAA Coral Reef Conservation Program (CRCP) and the Great Barrier Reef Marine Park Authority (GBRMPA) collaborated to produce a 4-day workshop to build capacity for responding to climate change by training coral reef managers, researchers, and stakeholders on the information presented in the Guide. The *Responding to Climate Change: A Workshop for Coral Reef Managers* training sessions teach international experts in coral reef management about climate change impacts on coral reefs, ecological resilience, and strategies for mitigating and managing future impacts (Figure 1.3).

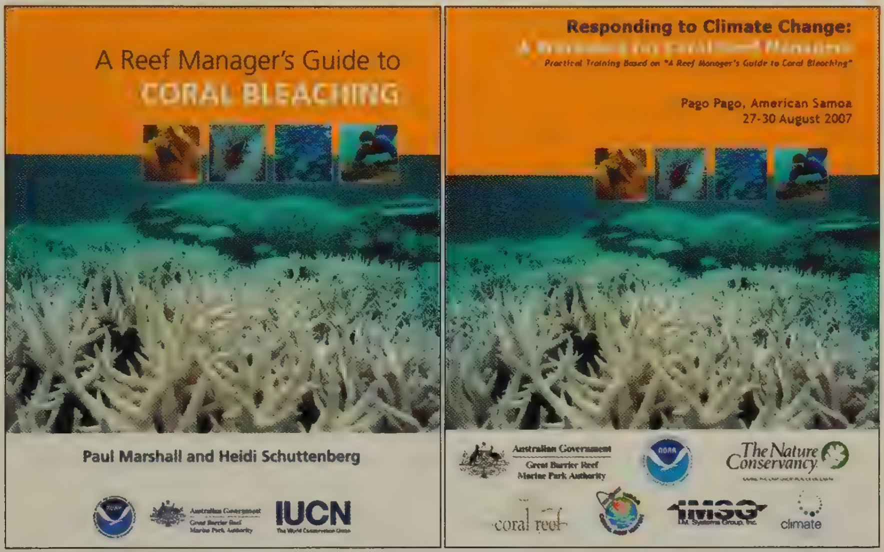

A Reef Manager's Guide to
CORAL BLEACHING
Paul Marshall and Heidi Schuttenberg
IUCN
Responding to Climate Change:
A Workshop for Coral Reef Managers
Practical Training Based on "A Reef Manager's Guide to Coral Bleaching"
Pago Pago, American Samoa
27-30 August 2007
The Nature Conservancy
coral reef
IMSG
climate

*Figure 1.3. Concerns about the effects of coral bleaching on reefs prompted publication of* A Reef Manager's Guide to Coral Bleaching *(left) and preparation of materials such as* Responding to Climate Change: A Workshop for Coral Reef Managers *(right). Source: NOAA Coral Reef Watch.*

More than 60 coral reef managers and scientists from Southeast Asia, Australia, and the Pacific islands, representing 8 nations, participated in two workshops in 2007 held on Australia's Great Barrier Reef at Lady Elliot Island and at Pago Pago, American Samoa. Through presentations, interactive discussions and exercises, and in-water field activities, the workshops provided participants with the skills and tools they need to adapt their management programs to address the growing threat climate change poses to coral reefs, such as predicting where coral bleaching will occur, measuring coral reef resilience and assessing the socioeconomic impacts of coral bleaching. Participants shared strategies and local management actions and participated in exercises that planned draft coral bleaching response plans and hypothetical Marine Protected Areas that emphasize resilience to climate change.

In addition to the Responding to Climate Change workshops, from 2005 to 2007 NOAA conducted nine Satellite Tools Training workshops in the Philippines, Palau, Mexico, Belize, Tanzania, and the U.S. Virgin Islands, in partnership with the World Bank/Global Environment Facility (WB/GEF) Coral Reef Targeted Research Program (CRTR). These workshops trained a total of 160 coral reef managers and scientists from more than 13 nations on state-of-the-art satellite-based monitoring products for predicting mass coral bleaching. These capacity-building trainings enable domestic and international reef managers to improve their understanding of how NOAA satellite data can help them monitor conditions that cause coral bleaching. This knowledge helps trainees improve research and management of their coral resources in the face of future coral bleaching events and climate change.

## 2005 CARIBBEAN CORAL BLEACHING EVENT

In 2005, coral reefs in the wider Caribbean suffered a widespread and severe bleaching event resulting in extensive coral mortality in much of the region. Persistent elevated SSTs caused an unprecedented bleaching event that stressed coral communities, many of which were later killed by disease or bleaching-related stress. The lingering effects of the event continue to degrade and kill corals in many locations. The USCRTF collaborated to mobilize efforts across the Caribbean to monitor, assess, and research short- and long-term impacts of the bleaching event. The USCRTF Bleaching Committee coordinated the efforts of NOAA, the National Aeronautics and Space Administration (NASA), the Department of the Interior (U.S. Geological Survey and National Park Service), other government agencies, non-governmental partners, university researchers, and local managers. Results of more than 3,600 bleaching observations from 100 researchers in 28 jurisdictions indicate 2005's elevated ocean temperatures produced the most widespread, intense bleaching and perhaps the highest mortality ever documented in the Caribbean.

Most hermatypic, or reef building, tropical corals host symbiotic algae called zooxanthellae, which live inside their tissues. Coral bleaching is the temporary or permanent loss of zooxanthellae from the coral, which can be caused by many types of physiological stress (e.g., ultraviolet rays, excessive warm or cold water temperatures, bacterial infection, etc.). However, widespread mass bleaching events, including the 2005 Caribbean bleaching event, are caused by persistent elevated sea water temperatures and can result in widespread mortality of coral reefs throughout the world. The 2005 bleaching was the result of the most intense high temperature stress ever observed in the Caribbean (from both the 20-year satellite record and the 100-year instrumental record; Figure 1.4).

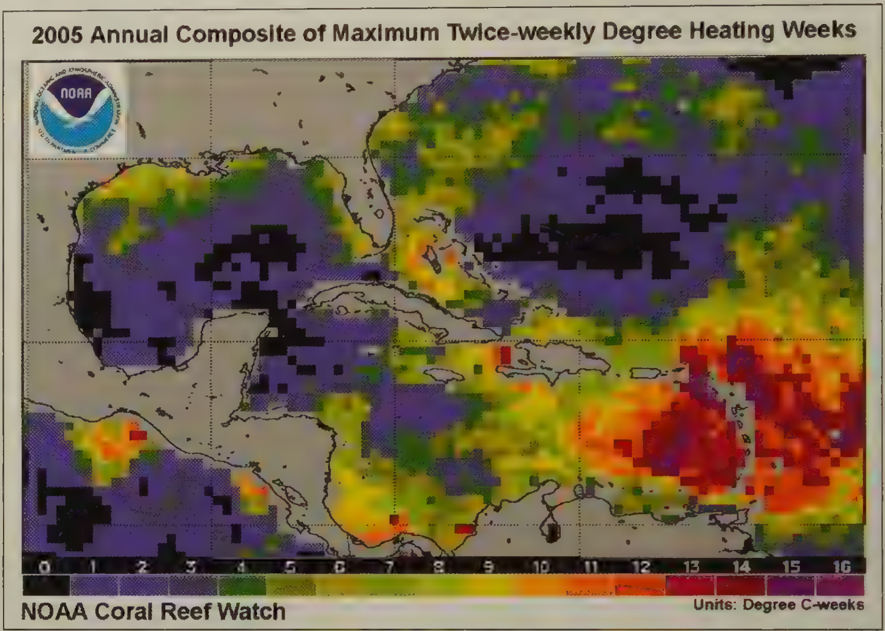


*Figure 1.4. Maximum annual coral bleaching Degree Heating Weeks (DHWs, °C-weeks) for the Caribbean region during 2005. Each DHW represents one week of temperatures 1°C above the maximum highest monthly average. Coral bleaching is expected to occur at DHW values above 4; significant mass bleaching and related mortality is expected at DHW values above 8. Source: NOAA Coral Reef Watch.*

NOAA e-mailed the first Satellite Bleaching Alerts for the 2005 Caribbean bleaching event in response to high temperatures detected in the Florida Keys in August 2005, and for Puerto Rico and the USVI in September 2005. During the 2005 event, the thermal stress detected by satellites in most of the Caribbean exceeded values known to trigger mass bleaching and reached nearly twice this threshold value around the northern Lesser Antilles.

The Global Coral Reef Monitoring Network's report, *Status of Caribbean Coral Reefs after Bleaching and Hurricanes in 2005*, which represents the work of scientists throughout the Caribbean basin, was released in January 2008 at the kick-off meeting for the International Year of the Reef 2008. The report is available at http://www.gcrmn.org.

## ENDANGERED SPECIES ACT LISTING OF CARIBBEAN CORALS IN THE GENUS *ACROPORA*

In May 2006, staghorn coral (*Acropora cervicornis*) and elkhorn coral (*Acropora palmata*), once the major reef building coral species in the Caribbean Sea, were formally listed as threatened under the Endangered Species Act (ESA; Figure 1.5). This marks the first time a coral has been listed as endangered or threatened under the ESA since its inception in 1973. According to the act, a species is considered endangered if it is in danger of extinction throughout all or a significant portion of its range. A species is considered threatened if it is likely to become an endangered species in the foreseeable future.

There are more than 110 species of Acropora worldwide. Only three species, *A. cervicornis*, *A. palmata* and *A. prolifera* (a hybrid of *A. cervicornis* and *A. palmata*), occur in the Caribbean and off the coast of Florida (Bruckner and Hourigan, 2002). Staghorn and elkhorn corals were once two of the most abundant and ecologically significant species of scleractinian, or hard coral, in the Caribbean. As recently as three decades ago these corals dominated reef environments at shallow and intermediate depths (0-15 m) where their unique branching characteristics and rapid growth rates produced dense thickets that not only played a vital role in reef accretion, but provided important habitat for numerous reef-associated animals (Acropora Biological Review Team, 2005). The structural and ecological roles of acroporid corals in the Caribbean are unique and cannot be fulfilled by other coral species (Bruckner, 2002). At the current reduced abundance, it is highly likely that both these ecosystem functions have been greatly compromised (Bruckner, 2002).

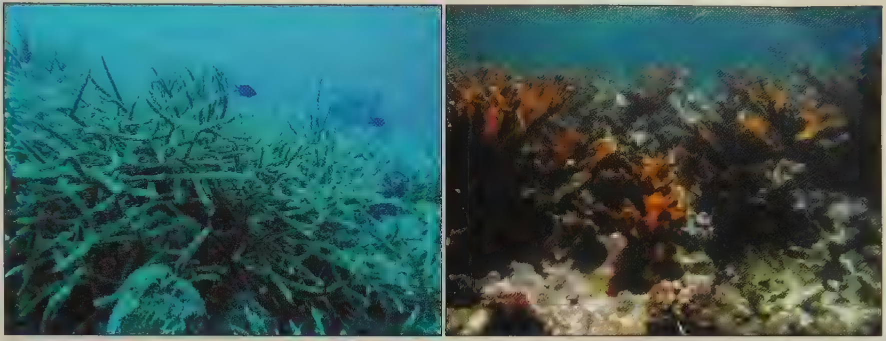


*Figure 1.5. Two species of Caribbean coral, staghorn coral (left) and elkhorn coral (right) were listed as threatened under the U.S. Endangered Species Act in 2006. Photos: NOAA/CCMA Biogeography Branch.*

The 1980s began a period of steep decline for staghorn and elkhorn corals, with both experiencing extreme population losses and serious reductions in spatial distribution within their historical range (Bruckner, 2002). In areas like Florida, Jamaica, Belize and the USVI, acroporid populations suffered losses of 90% or more (Acropora Biological Review Team, 2005). Today in areas where dense populations once stood, there are few, if any, individuals remaining. A number of stressors are implicated in this die-off, the most significant include disease outbreaks, temperature-related stress such as bleaching, and hurricane damage (Precht et al., 2004). Other factors influencing the decline are predation and injuries resulting from other anthropogenic stressors like anchoring and ship groundings.

The 2006 ESA listing is the latest step in the long process to formally protect remaining acroporid colonies. Efforts to list staghorn and elkhorn corals began as early as 1991, when both species were identified as candidates for listing under the ESA. According to NOAA's National Marine Fisheries Service (NMFS) a Candidate Species is, "any species being considered by the Secretary [of Commerce or Interior] for listing as an endangered or a threatened species, but not yet the subject of a proposed rule" (50 CFR 424.02). Such a designation does not grant any procedural or substantive protections under the ESA.

Six years later, both species were removed from the candidate list when NMFS failed to present sufficient documentation concerning the biological status and threats facing both species that were required for inclusion in the 1997 Candidate Species List (Hall, 2006). However, using information obtained from a 1998 analysis, both species were again added to the ESA Candidate Species List only to be transferred to the Species of Concern List in early 2004. A species of concern is an informal term referring to a species that might be in need of conservation actions, but for which there is not enough information available to determine if a formal listing is necessary. Neither Candidate Species nor Species of Concern receive legal protection under the ESA (NOAA Fisheries Office of Protected Resources, http://www.nmfs.noaa.gov/pr/species/concern/).

Later in 2004, the Center for Biological Diversity petitioned NMFS to list staghorn corals, elkhorn corals and *A. prolifera* as threatened or endangered. After a lengthy public comment period, a thorough scientific review aimed at establishing the species' status and an evaluation of current protection efforts under way at the time to protect both species, NMFS determined that staghorn and elkhorn corals were indeed likely to become endangered within the foreseeable future throughout their range (Hall, 2006). As a result, NMFS found that listing both species as threatened was warranted. Additionally, NFMS determined that the hybrid, *A. prolifera,* did not meet the definition of a species under the ESA, and therefore it did not warrant listing.

Ultimately, the ESA listing is intended to lessen the threats affecting both coral species until protection is no longer needed and both species are recovered or restored to a level at which they can sustain themselves without additional legal protection (Bruckner and Hourigan, 2002). To achieve these objectives, the ESA requires certain strategies be implemented soon after listing. For example, the act mandates that NMFS identify and designate critical habitat for the listed acroporids. Critical habitats are specific areas within the geographic range of the species that contain the physical or biological features essential to the conservation of the species and which may require special management considerations (Endangered Species Glossary, http://www.fws.gov/northeast/nyfo/es/esaglossary.pdf). Critical habitat regulations apply to any activities that are funded, authorized or carried out by the federal government. In addition to their responsibility not to jeopardize the existence of the listed species, these activities must not destroy or modify a species critical habitat.

In order to determine critical habitat, a request for data on the presence or absence of the two species was made to investigators currently working in the Atlantic and U.S. Caribbean (U.S. Virgin Islands, Puerto Rico, Navassa, Florida, and the Gulf of Mexico). Submitted data are being compiled into a centralized Geographic Information System (GIS) database to be used for mapping and delineating known current habitats. Final products will include Federal Geographic Data Committee compliant metadata and digital GIS maps of the current spatial distribution of live staghorn and elkhorn corals throughout the Atlantic and U.S. Caribbean (Figure 1.6).

NMFS is also required to develop a recovery plan. Recovery is a process by which listed species and their ecosystems are restored and their future is safeguarded such that ESA provisions are no longer necessary. At a minimum the plan must include site-specific management actions that foster recovery and outline objective, measurable criteria that would result in a determination that the species be removed. Finally, the plan must include estimates of the financial costs associated with recovery (NOAA Fisheries Office of Protected Resources, http://www.nmfs.noaa.gov/pr/recovery/).

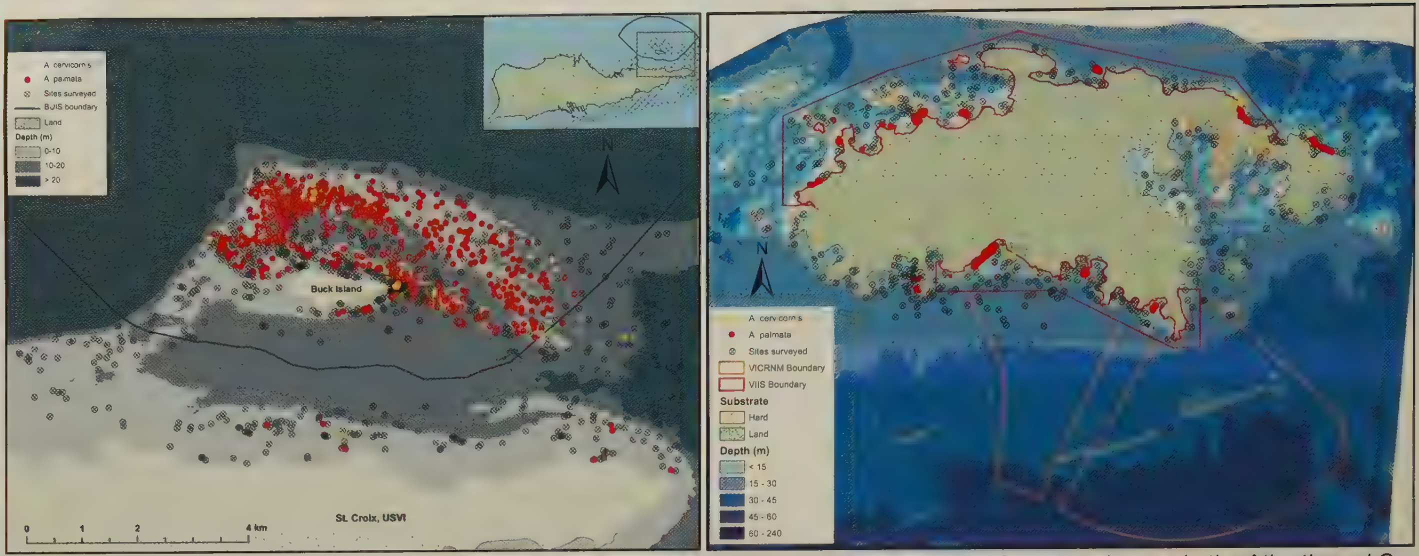


*Figure 1.6. Maps of the current distribution of corals in the genus* Acropora *have been compiled for several areas in the Atlantic and Caribbean, including at Buck Island near St. Croix (left) and the island of St. John, both of which are part of the USVI. Maps: C. Jeffrey.*

Although listing staghorn and ellkhorn corals as threatened does provide much needed protection, an endangered listing allows for more comprehensive conservation measures. When a species is listed as endangered it automatically receives certain protections (under section 9), including prohibitions against the take of the species, which includes direct removal, damage, injury and harassment. Because NMFS listed staghorn and elkhorn corals as a threatened species, the prohibitions of the ESA do not automatically apply. Therefore, NMFS must determine which of the section 9 ESA prohibitions are necessary to provide for the conservation of the species.

On December 14, 2007, NMFS published a proposed rule under section 4(d) of the ESA to extend all of the section 9 prohibitions with two exceptions. The exceptions provide for specific scientific research and restoration activities. The proposed rule was open for public comment until March 13, 2008. Once the proposed rule is finalized, the prohibitions will apply to all persons subject to the jurisdiction of the U.S.

ESA regulations only apply to the portions of the population that lie within U.S. waters. Both listed acroporid species cross international boundaries; only about 5-10 % of the region's current acroporid population resides within U.S. waters (Bruckner, 2002). Therefore ESA regulations have little or no impact on the vast majority of the population. On the other hand, the mandated recovery plan must address rehabilitation of the species throughout its range. As a result, the plan will identify actions that are necessary to recover the species in all countries in which both species are found, which can encourage international conservation measures. For further information about the ESA and the listing of these species please visit http://www.fws.gov/endangered/ and http://sero.nmfs.noaa.gov/pr/esa/acropora.htm.

## SOCIAL SCIENCE AND THE HUMAN DIMENSIONS OF CORAL REEF ECOSYSTEMS

During 2006 and 2007, the U.S. coral reef jurisdictions employed an increased focus on social science projects. Table 1.2 shows what projects have been conducted to date or are ongoing in the jurisdictions.

The external review for NOAA's Coral Reef Conservation Program recommended greater incorporation of social science research in November 2007, so an expanded focus on social science is expected in 2008 and 2009. Next steps include encouraging research in topics that are missing in the matrix, completing economic valuation studies for Puerto Rico and the U.S. Virgin Islands, and making increased connections between biophysical and social science data.

Understanding the value and human use of coral reefs is critical to reducing threats and sustaining healthy coral reef ecosystems. In particular, coral reef ecosystems in nearshore waters are vulnerable to the impacts of human activities, both directly by exploitation of reef resources and indirectly by deleterious land-based activities. The livelihoods and prosperity of people living in tropical coastal areas depend on, and influence, the conditions of marine resources. Coastal activities and their eventual impacts on reefs are inextricably linked, woven into the social, cultural, and economic fabric of regional coastal communities.

U.S. coral reef jurisdictions have implemented various research and monitoring projects to determine the economic valuation of reef resources and the impacts on local communities of coastal management activities such as MPA implementation. Improving our understanding of the underlying human motivations, beliefs, and perceptions regarding coral reef ecosystems is vital to the conservation and adaptive management of these valuable resources.

Between 2004 and early 2007, three major economic valuation projects were completed for the coral reefs of Guam, CNMI, and American Samoa. These studies, described below, used a combination of household interviews, economic

Table 1.2. Social science projects conducted in U.S. coral reef jurisdictions. Source: C. Loper.

| | USVI | Puerto Rico | Southeast Florida | Florida Keys | Navassa | Flower Garden Banks | Main Hawaiian Islands | Northwestern Hawaiian Islands | American Samoa | Pacific Remote Island Areas | Marshall Islands | Federated States of Micronesia | CNMI | Guam | Palau |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Commercial Fishing | | | | | | | | | | | | | | | |
| creel surveys | ● | ● | ● | ● | X | O | ● | ● | ● | X | ● | O | ● | ● | ● |
| knowledge, attitudes, and perceptions | ● | ● | O | ● | ● | O | ⊖ | ● | O | X | ● | ⊖ | O | ⊖[3] | ⊖ |
| economic impacts of coral reefs | ● | ● | ● | ● | ● | O | ● | ● | ●[2] | X | ● | O | ●[2] | ●[2] | O |
| dependency on reefs | ● | ● | ● | ● | ● | O | ●[2] | ● | ●[2] | X | ● | O | ●[2] | ●[2] | O |
| Recreational Fishing | | | | | | | | | | | | | | | |
| knowledge, attitudes, and perceptions | O | O | ● | ● | X | O | ⊖ | X | O | X | O | ⊖ | O | ⊖[3] | ⊖ |
| economic impacts of coral reefs | O | O | ● | ● | X | O | ●[2] | X | ●[2] | X | O | O | ●[2] | ●[2] | O |
| dependency on reefs | O | O | ● | ● | X | O | ●[2] | X | ●[2] | X | O | O | ●[2] | ●[2] | O |
| Subsistence Fishing | | | | | | | | | | | | | | | |
| knowledge, attitudes, and perceptions | O | O | X | X | ● | X | ⊖ | X | ⊖[4] | X | ● | ⊖ | O | ⊖[3] | ⊖ |
| economic impacts of coral reefs | O | O | X | X | ● | X | ●[2] | X | ●[2] | X | ● | O | ●[2] | ●[2] | O |
| dependency on reefs | O | O | X | X | ● | X | ●[2] | X | ●[2] | X | ● | O | ●[2] | ●[2] | O |
| non-market use valuation | O | O | X | X | ● | X | ●[2] | X | ●[2] | X | ● | O | ●[2] | ●[2] | O |
| Non-consumptive users (residents) | | | | | | | | | | | | | | | |
| knowledge, attitudes, and perceptions | ⊖[1] | ⊖[1] | O | ● | X | ● | ⊖ | X | O | X | ⊖ | ⊖ | O | ⊖[3] | O |
| economic impacts of marine reserves | ⊖[1] | ⊖[1] | O | ● | X | ● | O | X | O | X | O | O | O | O | O |
| non-market use valuation | ⊖[1] | ⊖[1] | ● | ● | X | ● | ● | X | ●[2] | X | O | O | ●[2] | ●[2] | O |
| Non-consumptive users (visitors) | | | | | | | | | | | | | | | |
| knowledge, attitudes, and perceptions | O | O | O | ● | X | ⊖ | ⊖ | X | O | O | O | O | O | O | ⊖ |
| economic impacts of marine reserves | O | O | O | ● | X | ⊖ | ⊖[1] | X | O | O | O | O | O | O | ⊖ |
| non-market use valuation | O | O | O | ● | X | ⊖ | ⊖[1] | X | ●[2] | O | O | O | ●[2] | ●[2] | ⊖ |
| Non Users | | | | | | | | | | | | | | | |
| knowledge, attitudes, and perceptions | O | O | O | O | O | O | ⊖[1] | ⊖[1] | O | O | O | ⊖ | O | O | O |
| non-market non-use valuation | O | O | O | O | O | O | ⊖[1] | ⊖[1] | O | O | O | O | O | O | O |

O not completed
⊖ partially completed
● completed
X not applicable

1. In progress
2. Commercial Fishing Panels
3. Economic Valuation Studies
4. Knowledge, Attitudes and Perceptions (KAP) study of the Florida Keys
5. Education Study

impact analysis, and stated preference surveys to estimate a total value for coral reef resources in the jurisdictions. Two more projects are planned for Puerto Rico and the USVI. Conducted by independent researchers, these studies will be used to highlight the economic importance of coral reefs to the economies and cultures of U.S. coral reef jurisdictions.

*The Economic Value of Guam's Coral Reefs*

This study, which included interviews of 400 local residents, revealed that over 90 percent of Guam residents make regular use of the beach and ocean for activities such as swimming, barbequing, fishing, and snorkeling. Approximately 40 percent of local residents fish on a regular basis, and fishing was identified to be more important as a social activity than for generating income. In economic terms, the value of Guam's coral reefs is derived from tourism, diving and snorkeling, fishing, property values, coastal protection, and biodiversity. The total economic value of Guam's reefs was estimated at $127.28 million per year, with tourism accounting for approximately 75 percent of this value. This report is available online at: http://www.coralreef.gov/taskforce/pdf/guam_susfin_palau.pdf.

*The Economic Value of the Coral Reefs of Saipan, Commonwealth of the Northern Mariana Islands*

This report estimated the total economic value of Saipan's reefs is $61.16 million per year, with tourism comprising about 70 percent of this value. The report concluded with three main recommendations, combining the findings of the valuation study and associated surveys with priorities identified in CNMI's Local Action Strategy. These recommendations include establishing measures to: address the issue of nonpoint and point source pollution; make use of the cultural importance residents place on marine ecosystems to improve coral reef management; and develop a comprehensive system of user fees for visitors of MPAs on Saipan. The report is available online at: http://cnmicoralreef.net/Saipan%20final%20report%20zip%20Feb2006.pdf.

*Economic Valuation of American Samoa's Coral Reefs and Adjacent Habitats*
This study estimated that the territory's coral reefs provide $5 million in benefits each year to American Samoan residents and visitors. While still significant, this value was lower than expected because tourism and recreational access to corals are limited, extensive man-made shoreline defenses have already been constructed due to beach sand and rubble mining, and the population is relatively small and poor. The American Samoa reef valuation study was conducted by a different set of researchers than the Guam and CNMI studies, which may have resulted in different methodologies for determining total economic values and may account for some of the differences in the totals for American Samoa versus Guam and CNMI. A copy of the report is available online at: http://doc.asg.as/crag/ASCoralValuation04.pdf.

The American Samoa Department of Marine and Wildlife Resources (DMWR), in partnership with the Coral Reef Advisory Group and NOAA, hosted a training workshop in Socioeconomic Assessment and Monitoring. The training was designed to improve manager and staff capacity to integrate socioeconomic analysis into the design, management, and monitoring of MPAs in American Samoa.

*Socioeconomic Monitoring through the Global Socioeconomic Monitoring Initiative*
In 2006, NOAA began coordination of the Global Socioeconomic Monitoring Initiative (SocMon). SocMon supports regional and national training workshops around the world to help reef managers incorporate socioeconomic assessments and monitoring into their reef management programs. This program has expanded to include domestic areas, including Puerto Rico, USVI, the Pacific territories and the FAS in 2007.

*Tortugas Integrated Assessment in the Florida Keys National Marine Sanctuary*
In 2006, NOAA initiated an integrated assessment of the Tortugas Ecological Reserve (TER) in the Florida Keys National Marine Sanctuary (FKNMS). The TER is a 151 $nmi^2$ (119 $km^2$) no-take zone created in July 2001 and located approximately 70 miles west of Key West. The Tortugas Integrated Assessment, which will be completed in 2008, involves a team of biophysical and social scientists assembled to assess the pre- and post-designation conditions of the TER and surrounding areas, as well as the impacts on both human and biophysical systems from establishment of the TER. This project, when complete, will provide important data regarding the effectiveness of MPAs. This study will also assess any short-term negative impacts to displaced users and identify shifts from consumptive to non-consumptive uses that may have occurred to offset losses that resulted from the displacement.

*Ethnographic Profiles*
Ethnographic community profiles related to fisheries and fish resources have been completed for the USVI and Puerto Rico, and the results can be found in the Puerto Rico and USVI chapters of this report.

*Commercial Fishing Panels in the Florida Keys National Marine Sanctuary (FKNMS): Years 7 and 8*
In the Florida Keys, four panels of commercial fishermen have been studied each year since 1998 to track impacts of fishing regulations. The panels were designed to monitor the impacts of the no-take regulations that went into effect on July 1, 1997 and establish a baseline panel for the TER, which went into effect on July 1, 2001. The four panels are: (1) general commercial fishermen not displaced from the no-take areas (used as a control group); (2) marine life collectors for the aquaria trade; (3) fishermen displaced from the Sambos Ecological Reserve; and 4) fishermen displaced from the TER. Information collected from these fishermen each year includes total catch, spatial distribution of catch, revenues, costs, and net earnings. An assessment based on eight years of data will assess whether the no-take areas in the FKNMS had any financial impact on the commercial fisheries. Information from the Tortugas panel is also being used in the Tortugas Integrated Assessment. The research team has recommended that the panels be converted to regionally-oriented panels and integrated with biological/ecological monitoring in the region.

*Knowledge, Attitudes, and Perceptions of Regulations and Management Strategies in the FKNMS*
In 2005, NOAA funded a ten-year replication of a baseline study completed in 1995-1996 by researchers at the University of Florida and the University of Miami's Rosenstiel School of Marine and Atmospheric Sciences, through a Florida Sea Grant Project. Baseline information was obtained on the knowledge, attitudes, and perceptions about regulations and management strategies being proposed for the FKNMS, in particular the no-take areas, which went into effect in 1997. The baseline and ten-year replication will assess changes in the knowledge, attitudes, and perceptions of FKNMS regulations and management strategies for three user groups: commercial fishermen, dive shop owners and operators, and members of local environmental groups. In 2006, the surveys of commercial fishermen and dive shop owners/operators were completed. A 100 percent response rate was achieved on a random sample of 300 commercial fishing operations, and a 95 percent response rate was achieved for the 65 dive shop owners/operators in the Florida Keys in 2006. The survey of members of local environmental groups began in December 2006, were completed in May 2007, and the analyses and reports are expected in 2008.

## IMPROVING THE USE OF MARINE PROTECTED AREAS IN CORAL REEF ECOSYSTEMS

The *Report on the Status of Marine Protected Areas in Coral Reef Ecosystems of the United States Volume 1: Marine Protected Areas Managed by U.S. States, Territories, and Commonwealths* (http://coralreef.noaa.gov/Library/Publications/cr_mpa_report_vol_1.pdf), was developed by NOAA in conjunction with federal, state, territory, and commonwealth partners from the U.S. Coral Reef Task Force (USCRTF). It was produced to help fulfill the goals and objectives of the U.S. *National Action Plan to Conserve Coral Reefs* (USCRTF, 2000) and the *National Coral Reef Action Strategy* (NOAA, 2002), and also helps to advance the goals of Executive Order 13158 on MPAs. Goal number five of the *National Coral Reef Action Strategy* calls for "improving the use of marine protected areas in coral reef ecosystems." Objective one under this goal area is to "conduct and support nationwide, state and territory assessments of the effectiveness and gaps in the existing system of U.S. coral reef MPAs." The report directly addresses that objective by providing an inventory and assessment of existing MPAs that have been established and are managed by the governments of the seven coral reef states and territories. It illustrates the goals and objectives of these areas; describes current efforts to manage them; recognizes common challenges to successful management; and identifies actions that can increase the effectiveness of MPA initiatives.

Efforts to manage a total of 207 MPAs across the seven coral reef jurisdictions are summarized in the report. The large majority of these MPAs (76%) are multiple-use areas that allow some level of extractive activity throughout the entire site. The remaining 49 MPAs include no-take areas in which the harvesting of marine resources is prohibited in parts or all of the MPA. One hundred and forty-seven (71%) of the MPAs were established to sustain, conserve, restore, and understand the coral reef ecosystems or ecosystem components they contain, while almost one quarter of them were established to support the continued extraction of renewable living resources. Of the 207 sites, 86% are permanent sites as opposed to conditional sites whose potential to persist must be considered after a set period of time. Nearly all of the sites (97%) provide constant protection throughout the year; only three percent are seasonal sites in which resources are protected during fixed periods of time. Most of the MPAs (78%) were established to provide an ecosystem scale of protection through which management measures are intended to protect all of the components and processes of the coral reef ecosystem within MPA boundaries. The remaining 22% target a particular habitat, species complex, or single resource.

Many of the MPAs in the assessment contain priority natural resources for coral reef conservation such as fish spawning areas (81 sites) and threatened or endangered species (164 sites). Only 20% of the MPAs (42 sites) have approved management plans (another nine are in development), suggesting that the development of plans to guide long-term MPA management is a challenge for many sites. However, this finding does not mean that management action is not occurring. Of the 194 sites that reported on management actions being implemented, approximately 42% have targeted research and outreach and education programs or activities, 45% have ongoing monitoring activities, and over 74% reported the existence of enforcement activities or programs.

Finally, MPA managers and practitioners from 126 of the sites identified several key challenges that impede the effective management of their MPAs. The most commonly noted challenges were enforcement (83%) and funding and resources (80%). Management capacity (76%), monitoring (65%), and public support (59%) are also challenges for a majority of sites. Other frequently identified challenges to management were lack of interagency coordination and insufficient communication between researchers and managers. These problems must be addressed to improve MPA management effectiveness.

### The Pacific Islands Marine Protected Area Community

It has been recognized that Marine Protected Area (MPA) managers in the Pacific Islands face a unique set of challenges including limitations in human and financial resources and isolation from other MPAs. While each MPA has its own strengths and issues, most share the challenge of capacity limitations. They also have in common the great distances between islands that restrict the ability of managers to learn from and apply approaches that have been successful elsewhere. These shared challenges inhibit Pacific Islands MPA systems from being as effective as possible. Nevertheless, many people feel the answers to today's challenges can be found in the islands. Traditional approaches to marine resource management across the Pacific Islands are thousands of years old. For MPA managers, the difficulty lies in building on these traditional approaches while adapting to modern technology and practices. Therefore, to play a successful role in MPA management, traditional and local approaches must be actively fostered, developed, and integrated into current MPA systems.

To address these unique challenges, more than 45 MPA leaders from around the Pacific Islands met in Tumon, Guam from August 26 to 31, 2005 to discuss their common strengths, challenges, and commitments to work together to support effective MPA management in the region (Figure 1.7). The meeting participants shared a common vision for a regional coordination network that would strengthen their individual and collective MPA efforts. The group committed to work together in an evolving regional Pacific Islands MPA Community (PIMPAC). The implementation of PIMPAC aims to build partnerships among Pacific Island MPA practitioners and to bring support to the region in order to strengthen MPA planning, develop-

*Figure 1.7. Pacific Island MPA leaders come together in Guam to initiate PIMPAC in 2005. Photo: PIMPAC.*

ment, management, and evaluation efforts and better conserve the marine resources of the Pacific Islands. Utilizing these partnerships, PIMPAC has developed a three-year strategic plan that focuses on four main activities:

1) providing training and technical assistance through regional workshops that offer skill development in specific topic areas and on-site technical support for site specific consultations (Figure 1.8);
2) building capacity at academic institutions to foster long-term development of MPA management curriculum and internships to build the next generation of MPA leaders;
3) sharing information and updates on recent MPA accomplishments, science, and funding or learning opportunities relevant to the region;
4) conducting exchange visits to foster peer-to-peer learning among MPA managers and provide opportunities for gaining hands-on experience.

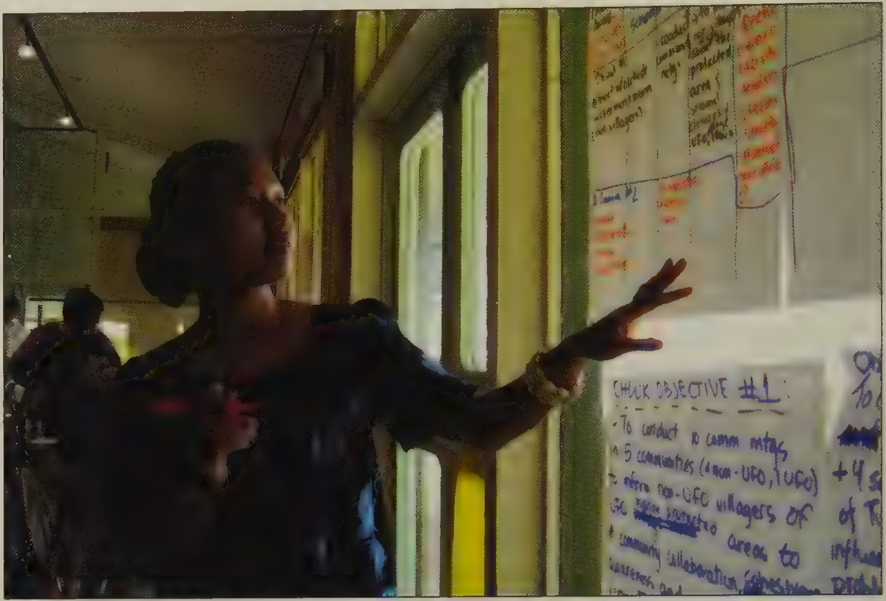


*Figure 1.8. Participants learn to assist communities in the development of management plans in Chuuk, 2006. Photo: PIMPAC.*

Through collaboration among PIMPAC partners, all of these activities are in progress. Presently, the main focus of PIMPAC training and technical assistance is stakeholder involvement in the development and management of sites, as well as management planning. However, future years will build on this foundation of management planning to provide in-depth technical support in other key MPA topics such as networking, monitoring, enforcement, outreach, and sustainable funding. PIMPAC activities carried out in 2006 and 2007 include; hiring a co-coordinator to support NOAA activities in Micronesia, development of a management planning guidebook, a regional training on management planning, on-site management planning technical assistance for 7 PIMPAC jurisdictions, development of a website/newsletter/list serve, three learning exchanges, and support for seven communications interns.

Finally, the efforts of PIMPAC strongly support several national and regional efforts to develop networks of effective marine protected areas. These efforts include; the U.S. Coral Reef Task Force, the U.S. National System of Marine Protected Areas, and the Micronesia Challenge. PIMPAC will continue to work to coordinate the implementation and establishment of effectively managed MPA sites to help achieve the goals of these large-scale efforts.

## THE MICRONESIA CHALLENGE

In January 2006, Governor Felix P. Camacho signed the Micronesia Challenge (MC), a commitment by the Chief Executives of Guam, the Commonwealth of the Northern Mariana Islands, the Federated States of Micronesia, the Republic of the Marshall Islands, and the Republic of Palau to effectively conserve at least 30% of nearshore marine resources and 20% of terrestrial resources across Micronesia by 2020.

The MC is the result of a process that began at the 7th Conference of the Parties in 2004 in Kuala Lumpur, Malaysia where world leaders committed to an increase in protected areas around the globe. At the 2005 Mauritius International Meeting High Level Event, the Presidents of Palau and the Seychelles called for the establishment of a Global Island Partnership. In November 2005 at the U.S. Coral Reef Task Force Meeting, Palau President Tommy E. Remengesau, Jr. invited the other chief executives from Micronesia to join him in committing to the MC. The MC was then officially announced to the international community by President Remengesau at the 8th Conference of the Parties to the Convention on Biological Diversity (CBD) held in March 2006 in Curitiba, Brazil.

The MC was conceived as a result of the deep commitment of these five leaders to ensure a healthy future for their people, protect their unique island cultures, and sustain the livelihoods of their island communities, by sustaining the island biodiversity of Micronesia (Figure 1.9). The MC also contributes to global and national targets set out in the Millennium Development Goals, the Johannesburg Plan of Implementation for the World Summit on Sustainable Development, the Mauritius Strategy for Small Island Developing States, the U.S. National Action Plan to Conserve Coral Reefs and the relevant Programmes of Work of the Convention on Biological Diversity.

To begin the process of implementing the Micronesia Challenge, 80 representatives from the five jurisdictions participated in a regional action planning meeting in Palau in early December 2006 (Figure 1.10). This meeting resulted in a comprehensive set of recommendations that were endorsed by the Chief Executives of Palau, CNMI and Guam at the

Western Micronesia Chief Executives' Summit in March 2006 and will be presented to the Presidents of the FSM and the RMI at the upcoming Presidents' Summit. Recommendations included the following:

- The establishment of a Steering Committee, comprised of a focal point from each of the jurisdictions;
- The budgeting for and recruitment of a regional coordinator and support staff;
- The development of an annual report;
- The development of a regional fund-raising strategy in coordination with national strategies for public and private funds to support the MC;
- The proposal that the Micronesia Conservation Trust house a single endowment in support of the MC;
- The commitment that each jurisdiction takes the appropriate steps to institutionalize the MC, including the engagement of traditional and community leaders; and
- Guam and each of the other four jurisdictions are designing their own strategies to implement the MC involving partnerships between Government agencies, NGOs and local communities. The MC Steering Committee is recruiting a regional coordinator to advance coordination of MC activities across the region.

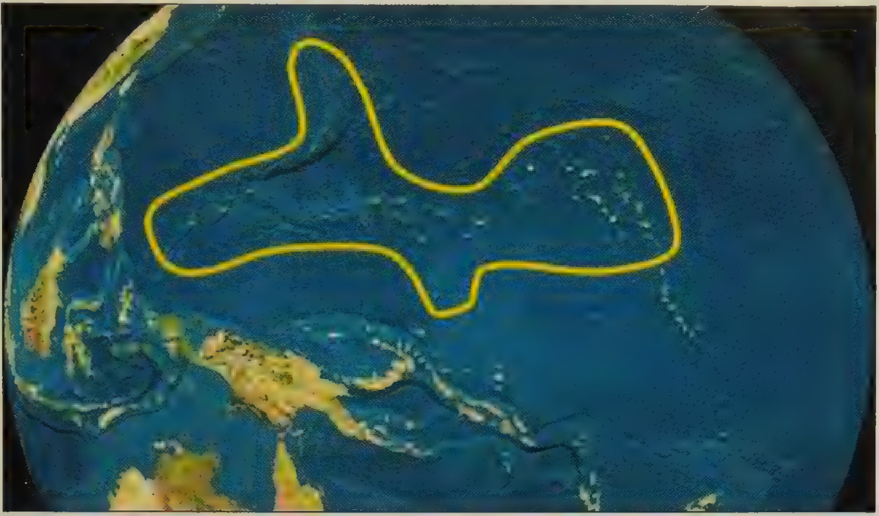


*Figure 1.9. The Micronesia Challenge aims to effectively conserve at least 30% of the nearshore marine resources and 20% of the terrestrial resources across Micronesia by 2020. Source: T. Leberer. Map: TNC.*

*Figure 1.10. President Tommy E. Remengesau, Jr. welcoming delegations from CNMI, FSM, Guam, and the Marshall Islands to Palau for the Micronesia Challenge Action Planning Meeting in December 2006. Photo: S. Menazza Olmsted.*

The MC Regional Support Team, with representatives from Conservation International (CI), the Secretariat of the Pacific Regional Environment Program (SPREP), NOAA, Rare (formerly RARE Center for Tropical Conservation), the Micronesia Conservation Trust (MCT), the Locally Managed Marine Area Network, the Community Conservation Network, the Pacific Islands Forum, The Nature Conservancy (TNC), and the U.S. Department of Interior has been formed to provide strategic assistance and external resources required for effective implementation of the MC.

## THE CORAL REEF ECOSYSTEM CONSERVATION AMENDMENTS ACT (CRECAA) OF 2007

In May 2007, the Department of Commerce presented Congress with the Coral Reef Ecosystem Conservation Amendments Act (CRECAA) of 2007, an Administration proposal with objectives that aim to strengthen and expand the tools needed to protect coral reef ecosystems for future generations. CRECAA reauthorizes and builds upon the Coral Reef Conservation Act (CRCA) of 2000, extending and increasing authorized funding levels and improving the ability of NOAA and DOI to be more effective at protecting and managing coral reef ecosystems.

Since the 2000 enactment of the CRCA, NOAA and the Coral Reef Conservation Program have worked to build the scientific capacity within a number of U.S. coral jurisdictions, as well as internationally. These efforts are focused on supporting several key objectives. They include: (1) map, monitor, characterize, restore, research, and assess the condition of coral reef ecosystems; (2) provide support for marine protected areas; (3) understand the threats to healthy coral reef ecosystems; and (4) promote public awareness and education on the value of and threats to coral reef ecosystems.

In order to update current coral legislation and tackle new threats, the CRECAA explicitly focuses implementation and management towards better understanding emerging issues (e.g., the association of coral disease and bleaching with climate change). The Administration's proposal would establish consistent guidelines for maintaining environmental data, products and information allowing for more effective information sharing. The most significant proposed changes add authorities to address injuries to coral reefs by providing authorization for funds to be placed into an emergency response fund, allow the government to hold the parties responsible for reef injuries liable for the costs of response and restoration, and provide NOAA and the Department of the Interior with various enforcement authorities. This would establish a damage recovery and enforcement process for all U.S. shallow coral reefs including those in National Wildlife Refuges, and increases the effectiveness of current authorities for recovering damages to reefs in National Parks and National Marine Sanctuaries. The CRECAA provides statutory authorization for DOI coral conservation activities and allows for direct removal of marine debris by the federal government. Finally, recognizing that NOAA's and DOI's existing partnerships are some of the most effective assets in addressing threats to corals, the bill is designed to facilitate existing partnerships with other agencies, governments and organizations.

NOAA anticipates reauthorization of the Coral Reef Conservation Act in 2008 and has been working closely with the House and Senate on development of a final bill. Senate bill S.1580 and House bill H.R.1205 both contain similar concepts to the Administration's proposal, and NOAA is hopeful that these concepts will be included in final legislation. The concepts as they currently appear in the Administration's proposal specifically call for the following nine additions or changes:

1. *Provide additional rationale as to the value of protecting coral reefs and coral reef ecosystems.*
   Additional context on the ecological, social and economic benefits of coral reefs and the threats to coral reef health supports the need for a suite of tools that will enable managers to better understand, manage, and protect coral reefs and coral reef ecosystems provided for by the CRCA.
2. *Provide tools to facilitate response to injury and restoration of coral reefs.*
   A major and all too common threat to coral reefs is mechanical injury, often from events such as ship groundings and improper anchoring. The CRECAA allows for better response to activities resulting in injury to coral reefs, with the costs borne by the parties responsible.
3. *Allow for stronger partnerships.*
   The bill builds on existing NOAA-DOI partner efforts and facilitates partnerships with other agencies, governments and organizations to better meet the directives and mandates of the Act.
4. *Highlight specific threats to coral reef ecosystems and responses to those threats.*
   Provides the authority to conduct a wide variety of activities to understand emerging issues related to coral bleaching and disease, climate change and vessel impacts to reefs.
5. *Data archive, access and availability.*
   The CRECAA of 2007 enhances previous legislation by providing for consistent guidelines for maintaining and sharing environmental data, products, and information that relate to coral reefs.
6. *Update Authorization of Appropriations to reflect the President's budget request and clarify the use of funds.*
   The CRCA specifies the amount of funding that can be used for program administration and overhead; these provisions are updated in the CRECAA.
7. *Amends definitions.*
   The definitions for "coral," "coral reef," and "coral reef ecosystem" are amended for accuracy, to reflect the limited use of the term "coral reef" in the regulatory sections, and to better reflect the scope of the coral reef ecosystem.
8. *Authorize a Coral Program for the Department of the Interior.*
   Enhances DOI's ability to provide technical assistance to states and territories and carry out their research and management objectives.
9. *Minor technical changes.*
   Minor changes including language and further clarification to illustrate that the conservation and management activities undertaken pursuant to the CRCA will have a wider international and global impact on coral reef ecosystems.

For the latest information about CRECAA and to read more about the bill, please visit http://www.coralreef.noaa.gov/welcome.html.

## FEDERAL FISHERIES MANAGEMENT

Coral reefs and associated habitats provide important commercial, recreational, and subsistence fishery resources in the U.S. and around the world, and represent a critical food source for many developing countries. Fishing plays a central social and cultural role in many island communities as well. The rich biodiversity of reefs also supports a valuable marine aquarium industry and promises rich genetic resources for pharmaceuticals. However, human population growth, the emergence of export fisheries, and the use of more efficient fishing equipment have led to overfishing[1] and fishing-related impacts on habitats and ecosystems. Increasing evidence shows overfishing significantly alters the ecological balance and contributes to the degradation of coral reef ecosystems.

Overfishing of coral reef resources is the most widespread threat around the world (WRI, 1998). Fishing has been identified as a high threat in every populated U.S. jurisdiction except the Commonwealth of the Mariana Islands (CNMI), where it is categorized as a moderate threat (Waddell (ed), 2005). Fishing was also identified by the states and territories in 2004 as one of five key threats that need to be addressed through specific local action strategies.

NOAA's Fisheries Service has been delegated authority under the Magnuson-Stevens Fisheries Conservation and Management Act to manage coral reef fisheries in federal waters sustainably, principally through fishery management plans developed by regional fishery management councils (FMC). The agency also has responsibility for ensuring the identification, conservation and enhancement of essential fish habitat (EFH), including through consultations with other federal agencies on their activities that may adversely affect such habitat in either state or federal waters. NOAA may also have direct management responsibilities for fisheries within National Marine Sanctuaries, often in collaboration with either the state management agency or the regional FMC.

The four regional fishery management councils that address coral reef fishery issues such as overfishing, habitat impacts, and bycatch are the South Atlantic FMC (http://www.safmc.net); the Gulf of Mexico FMC (http://www.gulfcouncil.org); the Caribbean FMC (http://www.caribbeanfmc.com); and the Western Pacific FMC (http://www.wpcouncil.org). Each of these organizations is active in conserving coral reef associated species within the federal waters under their jurisdiction through various measures, such as the establishment of seasonal and permanent fishery closures in federal waters to protect spawning aggregations or sensitive habitats, promulgation of regulations to control gear types, size limits, catch limits, implementation of actions to reduce interactions between fisheries and protected species, compilation and analysis of commercial and recreational catch data, assessments of socioeconomic and other factors that contribute to fishery issues, and other activities. The FMCs also serve as a resource for fishers by providing timely updates to both federal and state/territorial regulations, identification guides, educational materials and presentations, links to important scientific findings, information on aquaculture initiatives, and other tools. Some of these actions and resources are encompassed in the chapters of this report; further detail can be found on the FMC web sites.

---

[1] The term "overfishing" refers to significant depletion of reef species by commercial, recreational, or artisinal fisheries. It does not necessarily imply that a status of overfishing or overfished as defined by the Magnuson-Stevens Fisheries Conservation and Management Act has been determined.

## U.S. CORAL REEF TASK FORCE 10TH ANNIVERSARY

Given the frequency with which coral reef ecosystems span a broad range of geographical and organizational jurisdictions, coordination across federal, state, and local governments and with non-governmental organizations is essential for designing and implementing effective management and conservation solutions. Executive Order 13089 (Clinton, 1998) on Coral Reef Protection recognizes the value of coral reef ecosystems and directs the U.S. Government agencies to work independently "to ensure actions they authorize, fund, or carry out will not degrade the conditions of such ecosystems." Federal agencies are also directed to work together through the U.S. Coral Reef Task Force (USCRTF) to address, in a collective and strategic way, the threats to coral reef ecosystems and to lead, coordinate, and strengthen U.S. Government actions to conserve coral reef ecosystems, both domestic and international. Co-chaired by the Department of Commerce through NOAA and the Department of the Interior, the USCRTF membership includes senior leaders from 12 federal agencies, seven states, and territories and the three Freely Associated States (Figure 1.11). To implement the policies and requirements of the Executive Order, the USCRTF has provided a forum for coordinated planning and action among federal agencies, state and territorial governments, and non-governmental partners. To fulfill its mission, the USCRTF developed national strategies, targeted initiatives, and new partnerships to strengthen stewardship of the coral reef ecosystems in the United States and around the world. The USCRTF uses a variety of mechanisms to promote collaborative planning, priority-setting, coordination, and partnership building.

### U.S. Coral Reef Task Force Members

**Co-Chairs**

U.S. Department of Commerce, NOAA
U.S. Department of the Interior

**Federal Agencies**

U.S. Agency for International Development
U.S. Department of Agriculture
U.S. Department of Defense
U.S. Department of Homeland Security
U.S. Department of Justice
U.S. Department of State
U.S. Department of Transportation
U.S. Environmental Protection Agency
National Aeronautics and Space Administration
National Science Foundation

**States and Territories**

Commonwealth of the Northern Mariana Islands
Commonwealth of Puerto Rico
State of Florida
State of Hawai`i
Territory of American Samoa
Territory of Guam
Territory of the US Virgin Islands

**Non-Voting Members**

Federated States of Micronesia
Republic of the Marshall Islands
Republic of Palau

The USCRTF has played a key role in identifying the actions required to conserve U.S. coral reef ecosystems through the development of the U.S. *National Action Plan to Conserve Coral Reefs* (USCRTF, 2000) and the *National Coral Reef Action Strategy* (NOAA, 2002). The Plan provides 13 broad goals and objectives, while the Strategy focuses on key implementation measures. The Strategy, which has been in place for more than 5 years, needs a comprehensive reexamination and identification of ongoing and emerging priorities and targets to help guide the future work of the USCRTF. The USCRTF will lead this reexamination and launch a "Renewed Call to Action" at the end of 2008, to carry the legacy of ten years of the USCRTF into the future. The USCRTF, as a leader in collaborative action to conserve coral reefs, wishes to help create a community empowered to better manage and conserve our nations' coral reef ecosystems. More information about the USCRTF activities can be found at http://www.coralreef.gov/.

*Figure 1.11. USCRTF members attended a semiannual meeting in American Samoa in August 2007 which included a working retreat at Ofu in the Manua Islands. Photo: B. Dieveney.*

## INTERNATIONAL YEAR OF THE REEF 2008

Ten years ago, 1997 was declared the International Year of the Reef (IYOR). The first IYOR campaign was initiated in response to the increasing threats and loss of coral reefs and associated ecosystems such as mangroves and seagrass beds. IYOR 97 was a global effort to increase awareness and understanding of coral reefs, and support conservation, research and management efforts.

Ten years later, there continues to be an urgent need to increase awareness and understanding of coral reefs and their connectivity to land-based activities and to further conserve valuable coral reefs and associated ecosystems. Because of this need, the International Coral Reef Initiative designated 2008 as the second International Year of the Reef (IYOR 2008).

IYOR 2008 is intended to:

- Strengthen awareness of ecological, economic, social and cultural values of coral reefs and associated ecosystems;
- Improve understanding of the critical threats to coral reef ecosystems and generate practical and innovative solutions to reduce these threats; and
- Generate urgent action at all levels to develop and implement effective management strategies for conservation and sustainable use of these ecosystems.

While the 1997 IYOR served to raise the profile of coral reef issues and increase our collective awareness of the threats facing these valuable ecosystems, the 2008 IYOR aims to create a community with the knowledge and power to take action to address the threats faced by coral reef ecosystems. There are outstanding examples of successful past efforts to reduce threats and sustain coral reefs, but increased action over the next several years is critical.

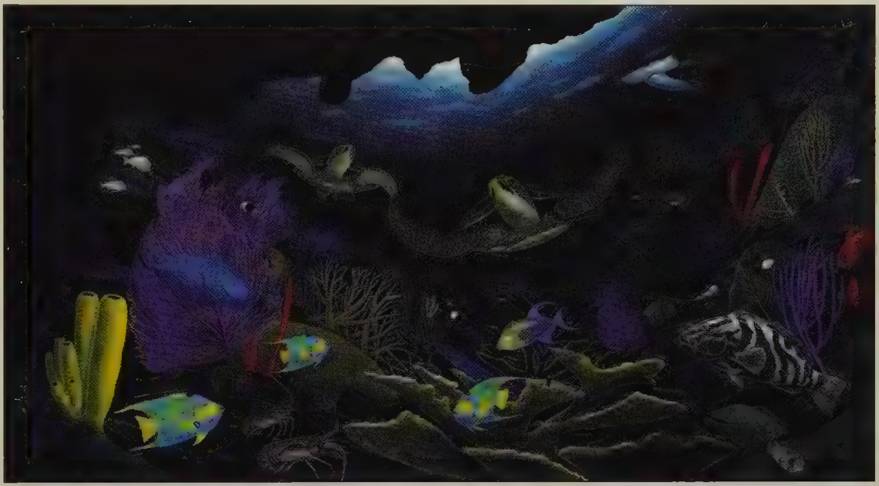


*Figure 1.12. The artist Wyland created this Caribbean reef scene in honor of IYOR and unveiled the painting at the USCRTF's 10th Anniversary meeting in Washington D.C. in February 2008. Artwork and photo: Wyland.*

Wyland, the official artist of IYOR 2008, unveiled his original painting "Year of the Reef" at the 19th U.S. Coral Reef Task Force meeting in Washinton D.C. (Figure 1.12). This partnership, which brings together Wyland's inspirational creativity and the collaborative nature of the U.S. Coral Reef Task Force, creates a new avenue through which we can inspire stewardship of our nations' coral reef resources.

To learn more about IYOR, please visit http://www.iyor.org/.

## REFERENCES

Acropora Biological Review Team. 2005. Atlantic Acropora Status Review Document. Report to National Marine Fisheries Service, Southeast Regional Office. March 3, 2005. 152 p + App.

Bruckner, A.W. 2002. Proceedings of the Caribbean Acropora Workshop: Potential Application of the U.S. Endangered Species Act as a Conservation Strategy. NOAA Tech Memo. NMFS-OPR-24.

Bruckner, A.W., Hourigan, T.F. 2002. Proactive management for conservation of Acropora cervicornis and Acropora palmata: application of the U.S. Endangered Species Act. Proceedings of the 9th International Coral Reef Symposium. Bali.

Bryant, D., L. Burke, J. McManus, M. Spalding. 1998. Reefs at Risk: A map-based indicator of threats to the world's coral reefs. World Resources Institute. Washington D.C.

Hall, H.D. 2006. Endangered and threatened species: final listing determinations for Elkhorn Coral and Staghorn Coral. Federal Registry 79: 26852-26872.

IPCC, 2007: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. http://www.ipcc.ch/ipccreports/ar4-wg1.htm

Kleypas, J.A., R.A. Feely, V.J. Fabry, C. Langdon, C.L. Sabine, and L.L. Robbins, 2006. Impacts of Ocean Acidification on Coral Reefs and Other Marine Calcifiers: A Guide for Future Research, report of a workshop held 18-20 April 2005, St. Petersburg, FL, sponsored by NSF, NOAA, and the U.S. Geological Survey, 88 pp.

Marshall, P. and Schuttenberg, H. 2006. A Reef Manager's Guide to Coral Bleaching. Great Barrier Reef Marine Park Authority, Townsville, Australia.

National Oceanic and Atmospheric Administration (NOAA). Recovery of Species under the Endangered Species Act (ESA). Available from the internet URL: http://www.nmfs.noaa.gov/pr/recovery.

National Oceanic and Atmospheric Administration (NOAA). 2002. A National Coral Reef Action Strategy: Report to Congress on implementation of the Coral Reef Conservation Act of 2002 and the National Action Plan to Conserve Coral Reefs in 2002-2003. NOAA. Silver Spring, Maryland. 120 pp. + appendix. http://www.coris.noaa.gov/activities/actionstrategy/action_reef_final.pdf

National Oceanic and Atmospheric Administration (NOAA). 2007. Proactive Conservation Program: Species of Concern and Candidate Species. Available from the internet URL: http://www.nmfs.noaa.gov/pr/species/concern/.

Precht, W.F., Robbart, M.L., and Aronson, R.B. 2004. The potential listing of *Acropora* species under the U.S. Endangers Species Act. Marine Pollution Bulletin 49: 534-536.

USCRTF (United States Coral Reef Task Force). 2000. The National Action Plan to Conserve Coral Reefs. USCRTF. Washington, D.C. 33 pp. + appendices. http://www.coralreef.gov/taskforce/pdf/CRTFAxnPlan9.pdf

U.S. Fish and Wildlife Service. 2005. Endangered Species Glossary. Available at http://www.fws.gov/endangered/glossary.pdf.

Waddell, J.E. (ed.), 2005. The State of Coral Reef Ecosystems of the United States and Pacific Freely Associated States: 2005. NOAA Technical Memorandum NOS NCCOS 11. NOAA/ NCCOS Center for Coastal Monitoring and Assessment'sBiogeography Team. Silver Spring, MD. 522 pp. http://ccma.nos.noaa.gov/ecosystems/coralreef/coral_report_2005/

Wusinich-Mendez, D. and C. Trappe, eds., "Report on the Status of Marine Protected Areas in Coral Reef Ecosystems of the United States Volume I." Silver Spring, MD: NOAA Coral Reef Conservation Program, February 2007. http://www.coralreef.noaa.gov/Library/Publications/cr_mpa_report_vol_1.pdf

# The State of Coral Reef Ecosystems of the U.S. Virgin Islands

Paige Rothenberger[1], Jeremiah Blondeau[2], Carrollyn Cox[3], Susan Curtis[4], William S. Fisher[5], Virginia Garrison[6], Zandy Hillis-Starr[7], Christopher F.G. Jeffrey[8], Elizabeth Kadison[2], Ian Lundgren[7], W. Jeffrey Miller[9], Erinn Muller[10], Richard Nemeth[2], Shona Paterson[11], Caroline Rogers[12], Tyler Smith[2], Anthony Spitzack[12], Marcia Taylor[13], Wesley Toller[14], Julie Wright[15], Dana Wusinich-Mendez[16] and Jeannette Waddell[8]

Additional Contributions: Jordan Gass[17], Nadine Noorhasan[18], David Olsen[19] and Douglas Westphal[20]

## INTRODUCTION AND SETTING

This report is the third in a series of assessments of the status of coral reef ecosystems in the U.S. Virgin Islands (USVI). The first assessment (Catanzaro et al., 2002) provided a broad overview of the status of USVI coral reef ecosystems, reported them to be in serious decline, and recommended enforcement of existing regulations and creation of no-take areas as the best actions to help reverse ecosystem declines. The second assessment (Jeffrey et al., 2005) identified several threats faced by coral reef ecosystems in the USVI, reported a continued overall decline in marine resources, and recommended for a second time that enforcement of existing regulations was the essential first step needed to address declining water quality, benthic habitats, and associated biological communities. This third assessment presents the current condition of coral reef ecosystems, describes the threats these marine ecosystems face and recommends additional actions based on data gathered between 2003 and 2007 by federal and territorial government agencies, non governmental organizations, academic institutions, and other stakeholders working in USVI coral reef ecosystems.

Coral reef ecosystems in the USVI comprise a mosaic of habitats, e.g., coral and other hardbottom areas, seagrasses, and mangroves, which house a diversity of organisms. Island communities depend on these biologically rich ecosystems for the important ecosystem services they provide such as shoreline protection and the support of valuable socioeconomic activities (e.g., fishing and tourism). However, human activities can and have destroyed or seriously degraded these same marine habitats upon which so much depends.

Coral reefs generally form fringing, patch, or spur and groove formations that are distributed in patches around three main islands of St. Croix, St. John, and St. Thomas and several smaller islands (Figure 2.1). The geology of these islands is dissimilar and has been previously described in great detail (Adey et al., 1977; Hubbard et al., 1993). Recent estimates of the spatial extent of coral reef ecosystems from Landsat satellite imagery indicate that coral reef ecosystems in the USVI cover approximately 344 $km^2$ (to 18 m depth) or 2,126 $km^2$ (to 183 m depth; Rohmann et al., 2005).

According to benthic habitat maps released by NOAA in 2001, coral reef and hardbottom habitats comprise 61%, submerged aquatic vegetation covers 33%, and unconsolidated sediments comprise 4% of shallow water areas less than 30 m deep in the USVI (Kendall et al., 2001; Monaco et al., 2001; http://ccma.nos.noaa.gov/about/biogeography/).

---

1 U.S. Virgin Islands Department of Planning and Natural Resources, Division of Coastal Zone Management, St. Croix, USVI
2 University of the Virgin Islands, Center for Marine and Environmental Studies, St. Thomas, USVI
3 Florida Fish and Wildlife Conservation Commission, Marathon, FL
4 County of Santa Barbara Office of Long Range Planning, Santa Barbara, CA
5 U.S. Environmental Protection Agency
6 U.S. Geological Survey, Florida Integrated Science Center, St. Petersburg, FL
7 National Park Service, St. Croix, USVI
8 NOAA National Ocean Service, Center for Coastal Monitoring and Assessment, Silver Spring, MD
9 National Park Service, St. John, USVI
10 Florida Institute of Technology, Biological Sciences Department, Melbourne, FL
11 University of Massachusetts Amherst, Department of Natural Resources Conservation
12 U.S. Geological Survey, Biological Resources Division, St. John, USVI
13 University of the Virgin Islands, Center for Marine and Environmental Studies, St. Croix, USVI
14 Accreditation Services International, GmbH, Bonn, Germany
15 U.S. Department of Agriculture Natural Resource Conservation Service, St. Croix, USVI
16 NOAA National Ocean Service, Coastal Programs Division, Silver Spring, MD
17 U.S. Virgin Islands Department of Planning and Natural Resources, Division of Coastal Zone Management, St. Thomas, USVI
18 U.S. Virgin Islands Department of Planning and Natural Resources, Division of Environmental Protection, St. Croix, USVI
19 U.S. Virgin Islands Department of Planning and Natural Resources, Division of Fish and Wildlife, St. Thomas, USVI
20 Naval Research Laboratory, Monterey, CA

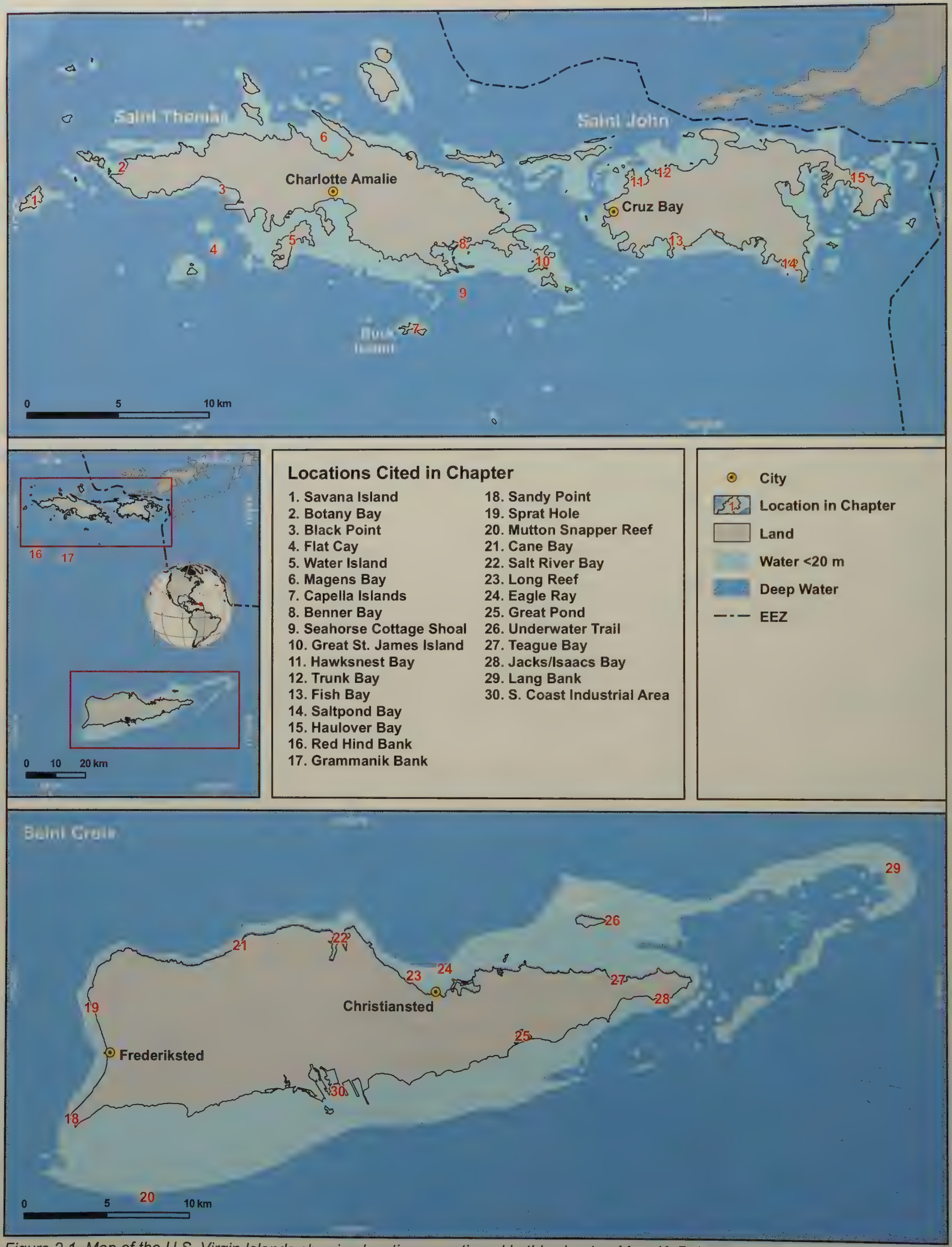

Saint Thomas
Saint John
Charlotte Amalie
Cruz Bay
Buck Island
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
0
5
10 km
16
17
0
10
20 km
Locations Cited in Chapter
1. Savana Island
2. Botany Bay
3. Black Point
4. Flat Cay
5. Water Island
6. Magens Bay
7. Capella Islands
8. Benner Bay
9. Seahorse Cottage Shoal
10. Great St. James Island
11. Hawksnest Bay
12. Trunk Bay
13. Fish Bay
14. Saltpond Bay
15. Haulover Bay
16. Red Hind Bank
17. Grammanik Bank
18. Sandy Point
19. Sprat Hole
20. Mutton Snapper Reef
21. Cane Bay
22. Salt River Bay
23. Long Reef
24. Eagle Ray
25. Great Pond
26. Underwater Trail
27. Teague Bay
28. Jacks/Isaacs Bay
29. Lang Bank
30. S. Coast Industrial Area
City
Location in Chapter
Land
Water <20 m
Deep Water
EEZ
Saint Croix
Christiansted
Frederiksted
18
19
20
21
22
23
24
25
26
27
28
29
30
0
5
10 km

*Figure 2.1. Map of the U.S. Virgin Islands showing locations mentioned in this chapter. Map: K. Buja.*

## ENVIRONMENTAL AND ANTHROPOGENIC STRESSORS

Threats and pressures affecting USVI coral reef ecosystems have been reviewed extensively by Rogers and Beets (2001), Catanzaro et al. (2002), Jeffrey et al. (2005) and Rogers et al. (in press). This section summarizes the major pressures on USVI coral reef ecosystems since 2003. Stressors that were described previously and have not produced major impacts since 2003 have been excluded from this report.

### Climate Change and Coral Bleaching

Increasing sea surface temperatures (SST) continue to stress USVI coral reefs (Figure 2.2). A major coral bleaching event occurred in the Caribbean during summer and fall 2005 and was associated with elevated SSTs that persisted for a period of 12 to 15 weeks, depending on location (http://www.osdpd.noaa.gov/PSB/EPS/SST/data2/dhwa.11.5.2005.gif). Reefs in the USVI experienced extensive and widespread bleaching during 2005, with more than 90% of coral cover bleached in some areas. On average, water temperatures surrounding the reefs were much higher than anytime during the previous 14 years (Miller et al., 2006; Lundgren and Hillis-Starr, in revision). Modeling of the SSTs that precipitated this event indicated that anomalously high SSTs were most likely a result of unprecedented forcing from modern climate change (Donner et al., 2007). A response was initiated by federal and territorial monitoring agencies when the potential impacts from the event became apparent. These efforts included teams from the National Oceanic and Atmospheric Administration (NOAA), U.S. Geological Survey (USGS), National Park Service (NPS), Virgin Islands Department of Planning and Natural Resources (DPNR) and the University of the Virgin Islands (UVI). What began as ad hoc monitoring at permanent and random study sites now forms the basis for one of the most intensively and extensively characterized coral bleaching events on record. Monitoring efforts from the event recorded not only the severe nature of the bleaching and subsequent disease and mortality, but variability in the response of corals across the USVI seascape. Although there was some recovery, episodic monitoring by NPS's South Florida Caribbean Network (SFCN) at four reefs in St. John and one at Buck Island Reef National Monument (BIRNM) in St. Croix after the bleaching event showed that bleached coral frequently became affected by white plague disease, ultimately resulting in > 50% loss of coral cover (Miller et al., 2006; NPS unpub. data) at long-term monitoring sites. Extensive monitoring by UVI as part of the DPNR Territorial Coral Reef Monitoring Program (TCRMP) at 25 sites across the USVI also showed that bleaching and the subsequent white plague disease outbreak caused from 10% to 90% loss of coral cover at sites in territorial and federal waters (Smith et al., in prep.). Major coral reef framework building species have been nearly extirpated at some sites. At BIRNM elkhorn coral experienced extensive bleaching and a loss of 53% cover for the species, after substantial regrowth throughout the 1990s (Mayor et al., 2006). The effects of bleaching and diseases on USVI coral reef ecosystems are dealt with in greater detail in the Benthic Habitats data section of this chapter.

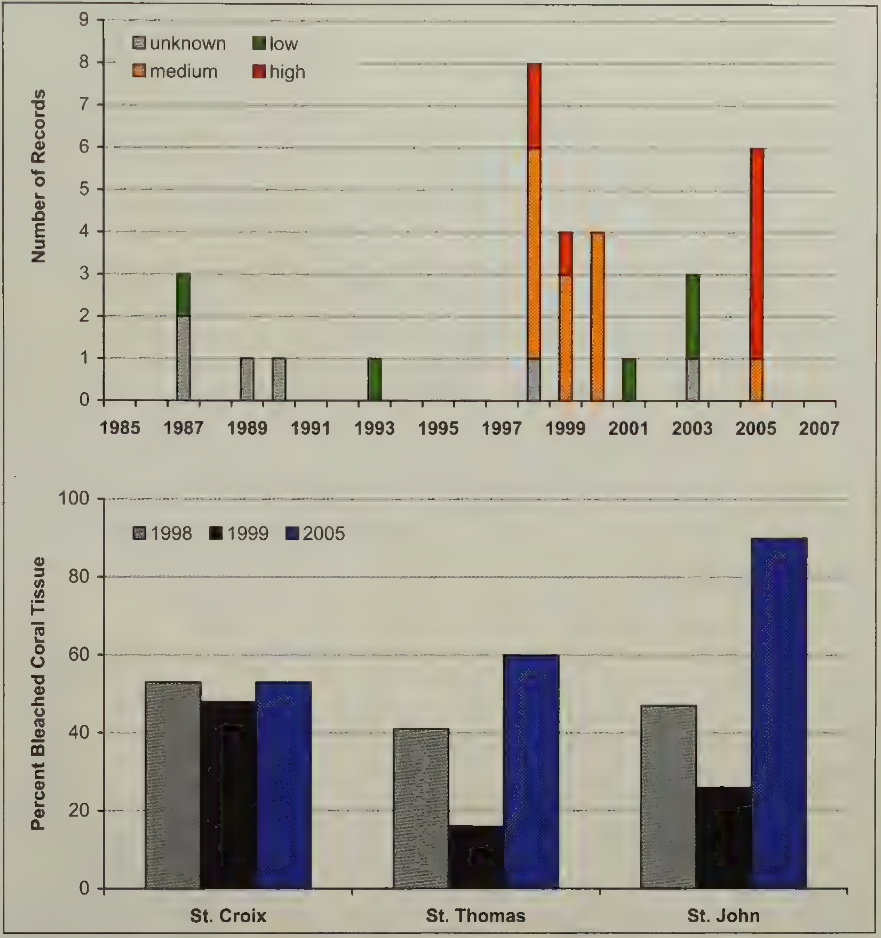


*Figure 2.2. Annual trends in coral bleaching in the USVI. Upper panel shows the number of bleaching reports by year and severity. Source: Reefbase 2005, http://www.reefbase.org. Lower panel shows the estimated percent of coral tissues that bleached in 1998-1999 and 2005. Bars represent the mean percent of sampled coral colonies that bleached by island and year. Source: Rogers and Miller, 2001; Nemeth et al., 2003; Nemeth et al., 2005; NOAA, 2005; Miller et al., 2006.*

In October 2005, as part of an existing bi-annual coral reef monitoring program for BIRNM and the St. Croix East End Marine Park (EEMP), data on the extent and severity of coral bleaching were collected by NOAA's Center for Coastal Monitoring and Assessment Biogeography Branch (CCMA-BB) and the NPS SFCN. Data from 94 randomly selected 100 $m^2$ transects over hardbottom habitats revealed that approximately 51% of live coral cover was bleached. Twenty-five of 30 coral species exhibited signs of bleaching, and bleaching was documented at all depths surveyed (1.5-28 m). Results of this project are described more completely in the Benthic Habitats data section of this chapter.

Partly in response to the regional bleaching event of 2005, NOAA's Coral Reef Watch Program sponsored a workshop in St. Croix in January 2006 entitled, *Satellite Remote Sensing Tools for Monitoring Thermal Stress Leading to Coral*

*Bleaching*. Attendees included federal and local resource managers and scientists from the British Virgin Islands (BVI), Puerto Rico and the USVI. Workshop participants were introduced to remote sensing tools for detection of environmental conditions that can lead to coral stress with the intent of increasing local capacity to respond to future bleaching events. Participants also discussed responses to the 2005 event, findings, needs and potential steps to improve future response efforts.

## Diseases

Diseases continue to significantly affect corals in the USVI. After the dramatic 2005 bleaching event, there was a 2,530% increase in disease lesions and 770% increase in denuded skeleton caused by disease over pre-bleaching levels. Mortality was primarily from white plague (NPS, unpub. data) and resulted in the loss of 51.5% live coral cover from more than 30 acres of coral reef (Figure 2.3; Miller et al., 2006). Surveys conducted as part of the TCRMP showed that the disease outbreaks were not confined to coral systems that were most severely bleached, as deep shelf edge sites that suffered little bleaching (5% of coral tissues) had high prevalence of white plague (6%) and suffered mortality similar to shallower, more heavily bleached sites (Figure 2.4). This indicates that high thermal stress can have effects that are decoupled from bleaching severity, and suggests that refuges from severe bleaching may not serve as refugia from mortality associated with high SSTs. More information on the effects of diseases on coral reef ecosystems in the USVI is presented in the Benthic Habitats section of this chapter.

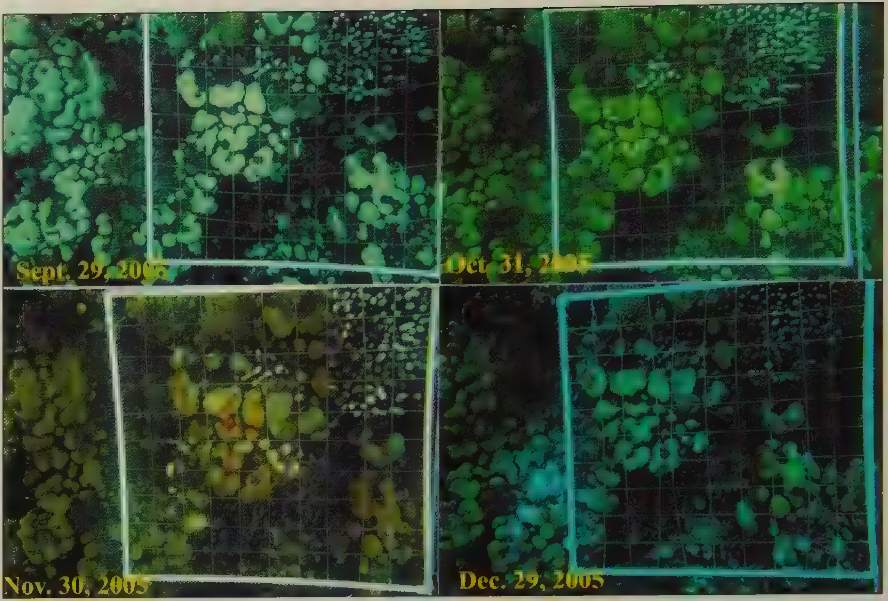


*Figure 2.3. Time series of bleaching and disease in* Montastraea annularis *and* Porites porites. *Bleached condition on September 2005, followed by partial recovery (October 2005) and disease mortality in November and December 2005. Source: adapted from Miller et al., 2006.*

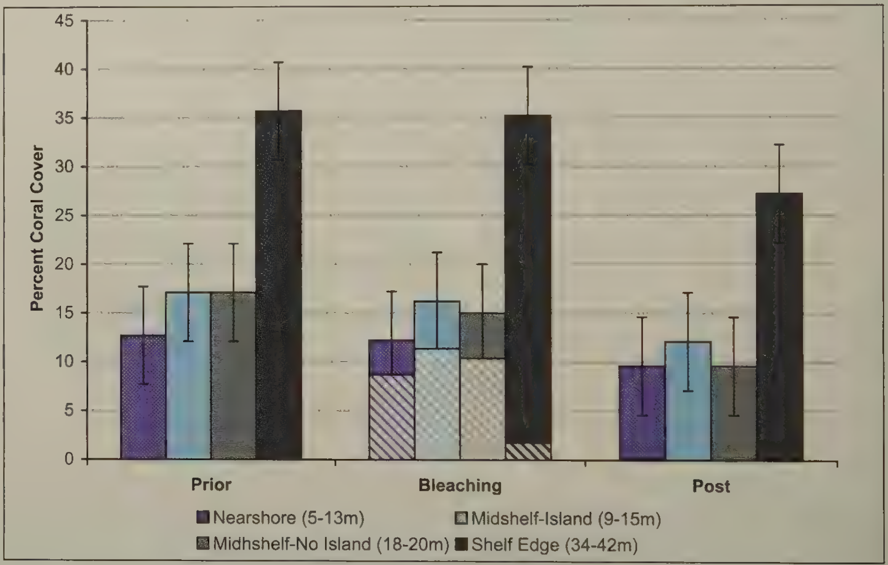


*Figure 2.4. Coral cover and percent of coral tissues bleached (diagonal stripe) at 16 sites before the 2005 mass bleaching event, during the event and after the event. Shallow nearshore and midshelf island-associated sites (7-15 m) and deeper midshelf and shelf-edge linear reef sites (15-40 m) showed remarkably different patterns of bleaching, but similar losses of coral cover after a white plague-like disease outbreak. Source: T. Smith, UVI-CMES.*

## Tropical Storms

The effects of hurricanes on USVI coral reefs have been well documented and reviewed, and tropical storms have been shown to be a major force structuring reef communities in the Caribbean (Rogers et al., 1997; Bythell et al., 2000; Rogers and Beets, 2001; Rogers and Miller, 2001; and Jeffrey et al., 2005). Hurricane Frances, a Category 4 storm that passed about 180 km north of the USVI in 2004, was the most recent hurricane to affect the USVI (Figure 2.5). No major damage to coral reef ecosystems from this storm was reported.

## Coastal Development and Runoff

Increasing pressures to develop land, combined with poor planning and regulation of development projects territory-wide, continues to be a major problem for the USVI. Watersheds in the territory have steep slopes and increasing amounts of impervious surfaces, which can create high velocity runoff and erosion. Sedimentation from unpaved roads can be 300-900% higher than that experienced in undisturbed watersheds (Rogers, 2006). Currently the territory utilizes a two-tier system, with different requirements for proposed developments in each tier. However, due to the topography of the islands, impacts from disturbances higher up in a watershed can be felt in coastal areas and may exacerbate impacts originating within the coastal zone. Additionally, lack of a Comprehensive Land and Water Use Plan for the territory makes effective planning for development and regulation of nonpoint sources of pollution extremely difficult. Published analyses of coastal development and associated impacts on the marine environment continue to be scarce in the USVI. An exception is the sediment monitoring program initiated in 2004 by UVI's Center for Marine and Environmental Studies (CMES).

Results from the CMES sediment monitoring program show a clear and significant onshore to offshore gradient (Figure 2.6), which suggests the potential impact of sedimentation on nearshore reefs is higher than on mid-shelf and offshore reefs. A similar onshore-offshore gradient was also found in a number of coral health indices, including bleaching prevalence and percentage of old mortality, indicating that sediment deposition may be a contributing factor in declining coral condition. Additional relationships were detected between sedimentation rates during the rainiest months and disease prevalence and the proportion of old mortality on nearshore reefs. These results suggest that the impact of heavy seasonal sediment loads can be significant on the nearshore environment. More detailed information on the CMES sediment study is included in the water quality section of this chapter.

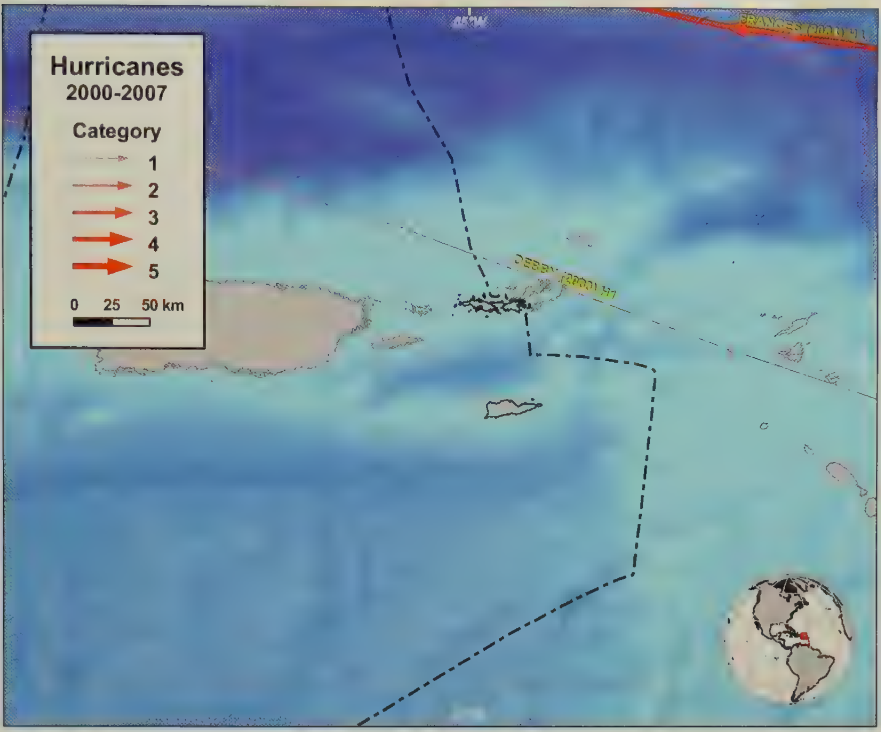


*Figure 2.5. Tropical storms affecting the USVI from 2000-2007. Storm name, year and intensity is indicated for each. Map: K. Buja. Source: http://maps.csc.noaa.gov/hurricanes/.*

## Coastal Pollution

Coastal pollution continues to affect coral reefs and other nearshore ecosystems. Bacterial contamination of coastal waters is a primary problem caused by numerous point and nonpoint source pollution discharges. Such discharges include failures at Publicly Owned Treatment Works which result in sewage bypasses into nearshore waters, failing septic systems and onsite sewage disposal systems, and the improper discharge of vessel waste directly into the water. The DPNR-Division of Environmental Protection (DEP) conducts the Virgin Islands Beach Water Quality Monitoring Program, a comprehensive beach monitoring and public notification program for beaches within the USVI jurisdiction. DEP developed this program to evaluate nearshore water quality represented by grab samples collected from designated beach bathing areas along the shorelines of St. Croix, St. Thomas and St. John. Since the program began in 2003, 43 beaches territory-wide have been sampled on a weekly basis. The information generated by this program has and continues to be used for public notification to minimize human health impacts from pathogens.

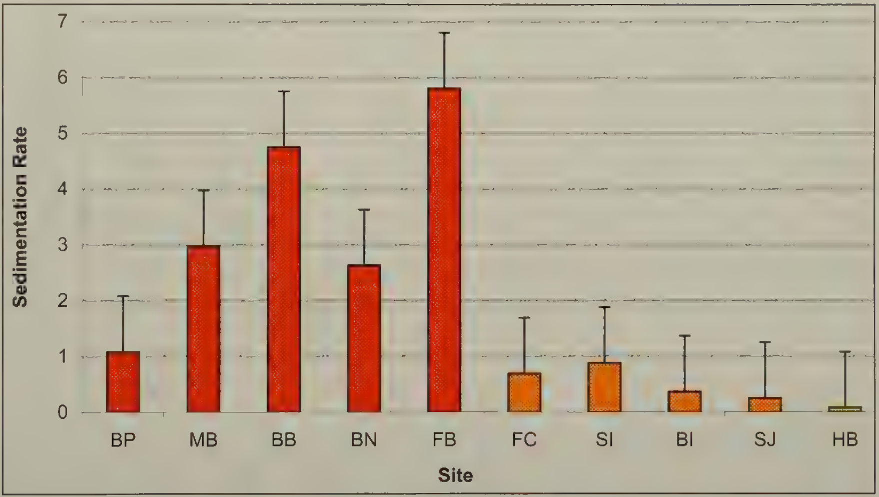


*Figure 2.6. Mean sedimentation rates for all sites (grouped from near-shore to off-shore). Red bars represent near-shore sites, orange bars mid-shelf sites and the yellow bar represents an offshore site. Source: J. Blondeau, UVI-CMES.*

Numerous beach advisories were issued in the USVI during the period of 2003-2006; DPNR-DEP does not close beaches. Beach advisories increased in 2004 by 26 days to 101 compared with the number of advisories in 2003. However, the number of beach advisory days in 2003 was much lower than in 1999, when the public was advised to avoid affected beaches for more than 300 days (Figure 2.7).

## Tourism and Recreation

Direct and indirect effects of tourism, recreation and associated development continue to affect USVI coral reefs. The history and impacts of tourism in the USVI were previously discussed in Jeffrey et al. (2005). Tourism continues to be a major component of the economy in St. Thomas and St. John but has declined in St. Croix since 2000 (Figure 2.8). Several factors have likely contributed to this decline including fewer airline flights and cessation of regular passenger cruise lines visiting Frederiksted in 2002. Smaller cruise ships continue to use the port in Gallows Bay, and larger cruise lines continue to use the Frederiksted pier for overnight bunkering to refuel.

BIRNM, which is managed by the NPS, was established in 1961 and expanded in 2001 to preserve and protect the unique elkhorn coral barrier reef. BIRNM remains St. Croix's number one tourist destination. NPS has six commercial companies that offer daytrips to the park year-round to snorkel, swim and enjoy the beach. There were over 109,000 commercial visitors and approximately 22,000 private visitors to BIRNM from 2003-2007. Numbers of visitors increased during this reporting period from 20,000 annually in 2003 to over 30,000 in 2006. BIRNM became one of the first fully protected marine areas in the NPS and in the USVI. The park ensures protection for all components of the marine ecosystem with the ultimate goal of promoting ecosystem recovery.

Adjacent to the BIRNM is the East End Marine Park, which is managed by the USVI government. In 2006 a system of 40 day-use moorings were installed within the EEMP to mitigate physical damage to park habitats. Moorings are available for the boating public and concessionaire use. Moorings were sited in heavily used areas where recreational boaters and fishers commonly anchored.

Beginning in 2007, a stateside-based dive operation, Nekton Diving Cruises, began bringing recreational divers to St. Croix. Utilizing a 34-passenger live-aboard dive vessel, the company has committed to improve 20 existing moorings around St. Croix. Nekton's Web site (http://www.nektoncruises.com/Departures/Schedule.aspx?B=Rorqual) shows weekly visits to St. Croix are scheduled until mid January of 2009.

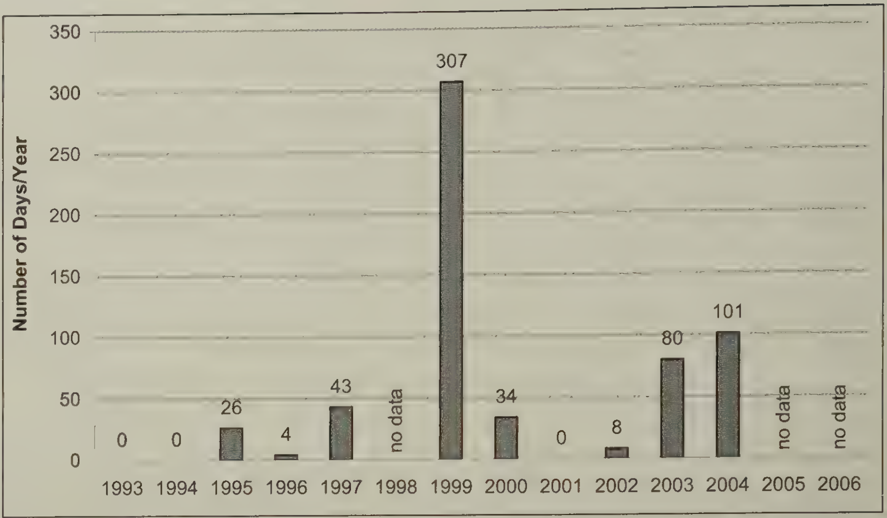


*Figure 2.7. Beach days affected by closings days or advisories in the USVI from 1993 to 2006. Source: USVI DEP; Natural Resources Defense Council 2005, http://www2.nrdc.org/water/oceans/ttw/sumvi.pdf.*

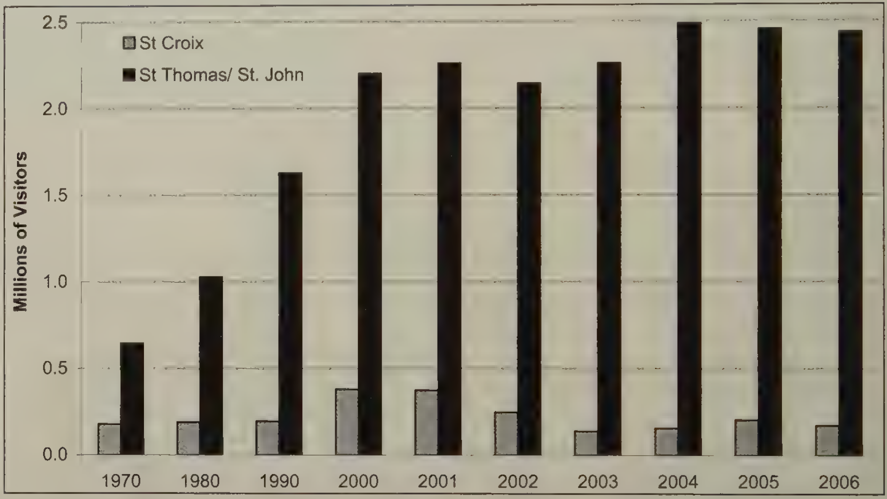


*Figure 2.8. Number of visitors to St. Croix and St. Thomas/St. John between 1970 and 2006. Source: USVI Bureau of Economic Research, http://www.usviber.org.*

## Fishing

Reef fisheries remain a challenge for managers in the territory. Under the current reporting period the Caribbean Fishery Management Council (CFMC) approved the Environmental Impact Statement for the Generic Essential Fish Habitat Amendment to the Fisheries Management Plans for spiny lobster, queen conch, reef fish, coral, and associated invertebrates and plants. As part of the process to amend the Sustainable Fisheries Act, scoping and working group meetings were held to solicit input and recommendations from fishers and the public. The draft amendment was prepared based on the meetings. Due to a lack of data on commercial fisheries for the territory, NOAA recommended extensive fishery closures for waters under CFMC jurisdiction. Although opposed to year-round fishery closures as management steps to protect impacted resources, the local government is considering the adoption of some CMFC preferred alternatives. Adoption of these alternatives would provide for compatible protection of resources in both federal and territorial waters. Alternative management strategies under consideration include: closed seasons for large-bodied grouper and snapper and a ban of specified duration on the capture of Nassau and Goliath grouper (Kojis, 2005).

Jeffrey et al. (2005) provided a comprehensive historical overview of the status of USVI reef fisheries. Since then, DPNR's Division of Fish and Wildlife (DPNR-DFW) has compiled and made available commercial fisheries-dependent and fisheries-independent data. DPNR-DFW coordinates two Cooperative Statistics Programs, the fishery-dependent Commercial Catch Reporting and Trip Interview Programs (TIP; port sampling) in order to monitor the fishery and gain information about its status. Information provided to the Commercial Catch Reporting program by fishers from the period 1975 through 2005 was compiled and analyzed during this report cycle. Catch trends for St. Thomas and St. Croix broken down by gear type are presented in Figure 2.9. DPNR-DFW's TIP collects biostatistical data from a subsample of commercial landings through the voluntary participation of fishers. Sampling under this program since 1980 has shown a continued decrease in size for red hind in the St. Croix fishery, with the average size of red hind caught near the minimum reproductive size for the species (DPNR-DFW, unpub. data). In contrast, data from this program indicate that spawning aggregation (SPAG) closures for the St. Thomas fishery have been effective and that average sizes of these fish caught from St. Thomas are approximately 10 cm larger than those caught in St. Croix (DPNR-DFW, unpub. data). Since these programs employ fishery-dependent data, they provide a description of the fishery but are limited in their ability to characterize fishery resources. Trends observed from these programs may indicate spatial or geographic differences in catch, gear variation and changes in fishing effort due to economic factors.

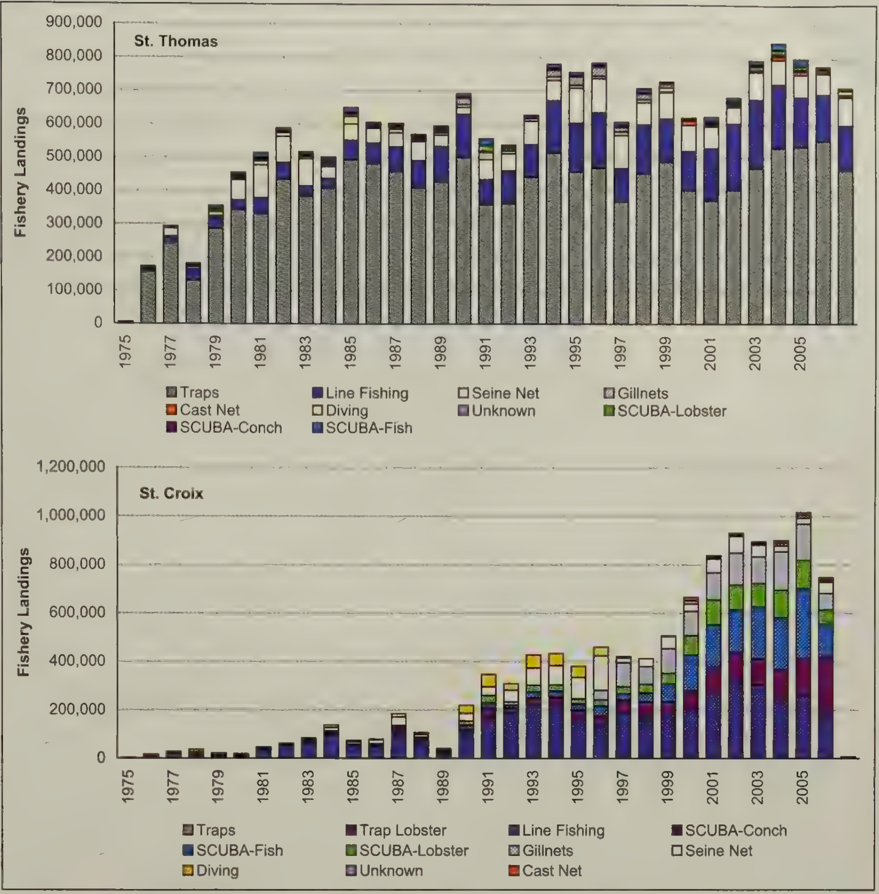


*Figure 2.9. Fishery catch trends by gear type in St. Thomas (top) and St. Croix (bottom) as reported to DPNR-DFW's Commercial Catch Reporting Program. Source: D. Olsen, DPNR-DFW.*

DPNR-DFW also coordinates the fisheries-independent Southeast Area Monitoring and Assessment Program Caribbean (SEAMAP-C) component to monitor fishery resources. SEAMAP-C is a collaborative effort between NOAA's National Marine Fisheries Service (NMFS), the Department of Natural and Environmental Resources in Puerto Rico and DPNR-DFW. The program's main goal is to "provide an integrated and cooperative program to facilitate collection and dissemination of fishery-independent information for use by government agencies, the fishing industry, researchers and others to enhance knowledge of marine fisheries and their associated ecosystems" (Griffin, 2005). The program uses a standardized sampling methodology across Puerto Rico and USVI to conduct assessments of reef fish, conch, and lobster stock on a three-year rotating schedule. Recent reviews of the SEAMAP-C program suggest that the current survey design is not providing data of the quality necessary to evaluate changes in fishery stocks (Whiteman, 2005; Pagan, 2004; Cummings et al., 2007). An evaluation of the SEAMAP-C sampling design has been proposed and implementation of any suggested changes to the design will be tested through subsequent pilot studies (Cummings et al., 2007). Detailed descriptions of methods and results are included in the Associated Biological Communities section of this chapter and in referenced publications for each program.

## Trade in Live Coral and Live Reef Species

In 2006, elkhorn (*Acropora palmata*) and staghorn (*A. cervicornis*) corals were listed by NMFS as threatened under the Endangered Species Act (ESA). This listing has the potential to affect coastal development regulation in the USVI, as nearshore coral reefs comprise the primary habitat for these species. Elkhorn and staghorn corals are important framework species, and their branching growth form provides significant habitat for a variety of reef organisms. These corals have, and continue to be, acutely impacted by physical damage (hurricanes, anchoring), bleaching associated with increasing SSTs and coral disease. While these species have made limited, localized recoveries (Mayor et. al., 2006) the general trend is one of continued decline due to the aforementioned factors compounded by additional anthropogenic stressors such as declining coastal water quality due to sedimentation, runoff and point source discharges. The continued loss of these reef-building species has likely altered the functionality of the territory's coral reefs and is especially troubling as the USVI depends on its reefs to support tourism and provide food, recreation and shoreline protection.

Currently, the *Acropora* recovery team is preparing a recovery plan for the species pursuant to section 4(f) of the ESA. The plan will outline strategies to conserve and protect the existing elkhorn and staghorn populations through documentation of species abundance, distribution, habitat requirements, genetic status and disease dynamics, and through outreach and education efforts (http://sero.nmfs.noaa.gov/pr/esa/acropora.htm). More information on the listing and potential regulatory impacts is found in the Current Conservation Management Activities section of this chapter.

## Ships, Boats and Groundings

Vessel impacts such as groundings, anchor damage and waste discharges continue to affect coral reef ecosystems in the USVI. One such example from St. John is the April 2002 grounding of a local inter-island ferry, the *Voyager Eagle*. The ferry ran aground on Johnson's reef in the Virgin Islands National Park (VINP; Figure 2.10). Three areas were identified by NPS staff as being injured by the grounding and subsequent removal of the vessel. NOAA's CCMA-BB is collaborat-

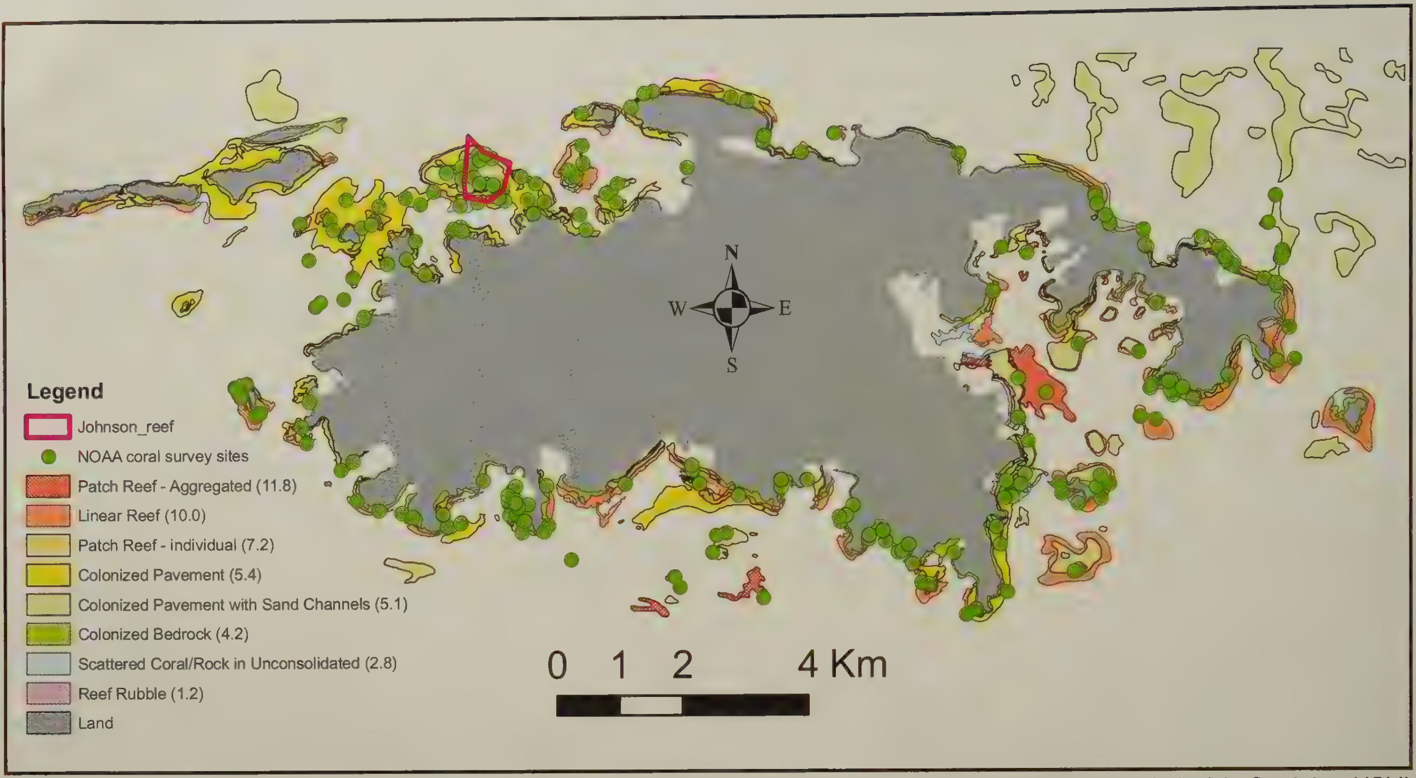

N
W
E
S
Legend
Johnson_reef
NOAA coral survey sites
Patch Reef - Aggregated (11.8)
Linear Reef (10.0)
Patch Reef - individual (7.2)
Colonized Pavement (5.4)
Colonized Pavement with Sand Channels (5.1)
Colonized Bedrock (4.2)
Scattered Coral/Rock in Unconsolidated (2.8)
Reef Rubble (1.2)
Land
0 1 2 4 Km

*Figure 2.10. Location of the vessel injury area, coral reef types, and NOAA benthic survey locations (green circles) in St. John, USVI. Numbers in parentheses are mean estimates of live coral cover for each reef type. Coral cover was determined from benthic surveys conducted at 183 locations during 2002-2006. Bold text indicates reef types that occur at the grounding site. At each survey location, data were collected from five replicate 1 m$^2$ quadrats randomly placed within a 100 m$^2$ belt transect. Reef types are from the "Benthic Habitats of Puerto Rico and the U.S. Virgin Islands" (Kendall et al., 2001). Map: C. Jeffrey.*

ing with NPS staff to develop estimates of coral cover within the areas damaged by the Voyager Eagle. Quantitative data derived from 1) benthic maps (Kendall et al., 2001) and 2) *in situ* monitoring of benthic composition (http://ccma.nos.noaa.gov/ecosystems/coralreef/reef_fish.html) are being used to estimate live coral cover in impacted areas. These estimates will be used during litigation and negotiation of compensation for damages caused by the grounding.

In addition to coral damage caused by groundings, vessel anchoring is a problem for USVI reefs. A report by Toller (2006) provides insight on the impacts of decades of damage caused by the anchoring of large vessels on the Frederiksted reef system in St. Croix. This area was used as an anchorage since colonial times. However, in 1994 two anchorages were established to the north and south of the Frederiksted pier despite information that noted the importance of this reef system to local fisheries. Toller (2006) investigated the extent of damage to the reef system to the north of the pier between 2004 and 2005. Extent of the damage was estimated at 21.2 hectares (ha) of reef crest with a maximum cross-shelf width of 256 m (Toller, 2006). Rugosity (a measure of the complexity of the reef surface), coral cover and coral species richness were all significantly reduced (43.5%, >87% and 54%, respectively; Toller, 2006) in the damaged area compared to control sites. Fish community structure, including the average and cumulative number of species, were both lower (20% and 19% respectively; Toller, 2006) than control sites. Results of this study show that anchor damage can dramatically affect the architecture of reef systems and the biological communities they support. This case study highlights the continuing need for planning and regulation of vessel anchoring in the USVI.

## Marine Debris

Like most developed areas, marine debris continues to be a problem in the USVI despite educational programs and community cleanups. Currently the only data about marine debris in the USVI is collected during the Ocean Conservancy's annual International Coastal Cleanup (ICC). The USVI has been participating in the ICC for 13 years. Approximately 900 volunteers across the territory participate in land and underwater cleanups associated with this event annually. Additionally, several groups conduct beach cleanups at specific sites around the islands throughout the year.

During the 2006 ICC, 1,083 volunteers removed 19,255 pounds of trash and debris from 53 miles of shoreline. In addition, 18 volunteers participated in underwater cleanups, removing 500 pounds of debris. The types of debris collected in the 2006 ICC were similar to debris types found around the world. The ten most numerous items found in the 2006 ICC all originate from shoreline recreational activities. The most numerous items were glass bottles, cap/lids, cans, plastic bottles and plates/utensils. Items from shoreline recreational and smoking-related activities comprise 92% of all items collected (Figure 2.11). Although some debris washes in from offshore sources, it represents a very small percent of total items collected.

## Aquatic Invasive Species

Aquatic invasive species are not recognized as a major threat in this jurisdiction.

## Security Training Activities

No security training activities currently occur in this jurisdiction.

## Offshore Oil and Gas Exploration

No offshore oil and gas exploration currently occurs in the USVI.

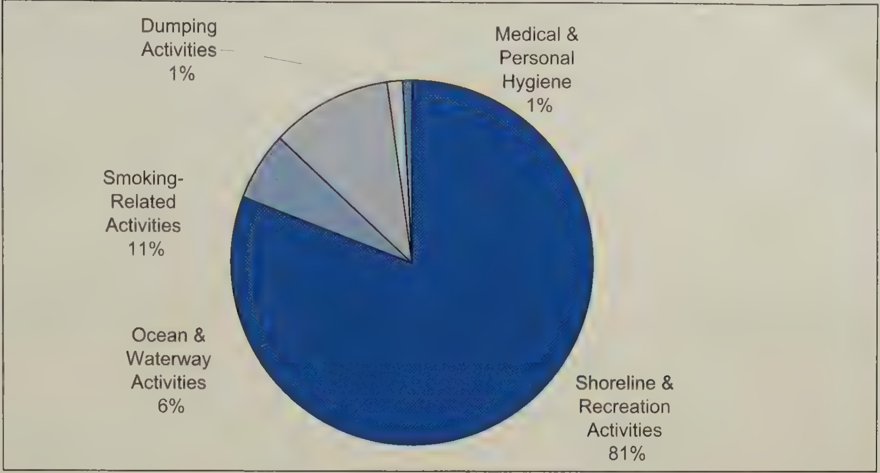


*Figure 2.11. Sources of marine debris collected as part of the 2006 ICC in the USVI. Source: M. Taylor, UVI-VIMAS.*

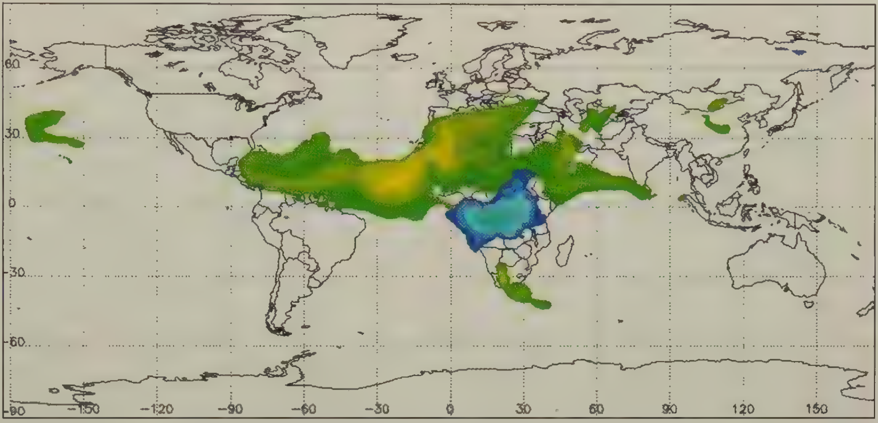


*Figure 2.12. Simulated distribution and composition of aerosols on June 23, 2007 showing transport of dust from the Sahel region of Africa across the Atlantic, to the Caribbean. Optical depth in images contoured at 0.2, 0.4, 0.8, 1.6, 3.2, and 6.4. Green and yellow shades indicate dust and blue indicates smoke from biomass burning. Source: Navy Aerosol Analysis and Prediction System (NAAPS) Global Aerosol Model courtesy of Douglas L. Westphal, Naval Research Laboratory.*

## Other

### *African Dust*

Every year, hundreds of millions of tons of eroded mineral soils (dust) are carried in the atmosphere from the Sahara Desert and Sahel in Africa to the Americas and Caribbean. The quantity of soil transported varies with global climate, tropical SSTs, regional meteorology, surface composition and land use in dust source regions. Saharan dust has been transported across the Atlantic for millions of years, impacting downwind ecosystems through deposition of nutrients to the Amazon Basin, red-clay soils to the limestone islands of the Caribbean, freshwater diatoms and phytoliths to the seafloor off the coast of West Africa, and iron that periodically triggers red-tides in the Gulf of Mexico. At times, a continuous cloud of Saharan dust extends from West Africa to Central and South America and north to the southeastern U.S. (Figure 2.12). Over the past 40 years, the quantity of dust has increased, and the composition of the dust cloud has been altered due to pesticide use, changes in land use, and burning of synthetic materials and biomass (fuel) in the dust source regions and in the areas over which they pass (Garrison et al., 2003 and 2006).

An international team of scientists led by the USGS is examining the contaminants carried with African dust and the role they may play in the degradation of Caribbean coral reefs and other downwind ecosystems (Shinn et al., 2000; Garrison et al., 2003 and 2006). Thus far, African dust has been found to carry viable microorganisms, including pathogens, nutrients such as iron, persistent organic pollutants and heavy metals. During dust conditions in the USVI and Trinidad, African dust contains 2-3 times as many microorganisms per volume as during non-dust conditions. Of those species identified to date, 25% are known plant pathogens and 10% are known opportunistic pathogens of humans (Griffin et al., 2001 and 2003). A coral disease pathogen, the fungus *Aspergillus sydowii,* has been identified in dust (Weir-Brush et al., 2004). Pesticides (such as chlordane, lindane, chlorpyrifos, endosulfans and dacthal), polycyclic aromatic hydrocarbons, and polychlorinated biphenyls have been identified in African dust air masses in the Caribbean (USVI and Trinidad) and in Africa (Garrison et al., 2005). These contaminants are known to be toxic at very low concentrations, to persist in the environment, to bioaccumulate in organisms, and to interfere with reproduction and immune function. Particularly troubling, at the most basic ecosystem level, some of these contaminants are known to shut down phytoplankton photosynthesis (Wurster, 1968).

## CORAL REEF ECOSYSTEMS—DATA-GATHERING ACTIVITIES AND RESOURCE CONDITION

This section focuses on resource monitoring activities, data collection and analyses, and summaries of published studies and data sets to provide an assessment of the condition of USVI coral reef ecosystem resources during 2004-2007. Information is presented to describe three functional or structural components of coral reef ecosystems: marine water quality and oceanographic conditions, benthic habitats, and associated biological communities (Table 2.1). A brief summary of ongoing research and monitoring programs, methods, results and discussion are presented for each ecosystem component. Locations of monitoring and research efforts are shown in Figure 2.13.

*Table 2.1. Data sets selected to describe the current condition and status of coral reef ecosystems in the USVI for the period 2004-2007. Bold type indicates new monitoring programs. Source: P. Rothenberger.*

| Ecosystem Component | Data Set | Source Agency | Objectives | Start Date | Frequency | Program Information |
|---|---|---|---|---|---|---|
| **Water Quality** | Water Temperature Monitoring at BIRNM | NPS | Basic abiotic monitoring | 1991 | Continuous | |
| | 2004 Integrated Water Quality Monitoring and Assessment Report for the USVI | EPA, DPNR-DEP | "To satisfy 305(b) and 303(d) requirements of the Federal Clean Water Act; to assess the water quality conditions of the Virgin Island's surface and ground water resources" | 1998 | Every two years | http://www.dpnr.gov.vi/dep/pubs/ |
| | 2006 Integrated Water Quality Monitoring and Assessment Report for the USVI | EPA, DPNR-DEP | "To satisfy 305(b) and 303(d) requirements of the Federal Clean Water Act; to assess the water quality conditions of the Virgin Island's surface and ground water resources" | 1998 | Every two years | http://www.dpnr.gov.vi/dep/pubs/USVI2006IWQAReport.pdf |
| | National Coastal Condition Report II (2005) | EPA, DPNR-DEP | To describe, summarize, and rate the overall ecological and environmental conditions of U.S. coastal waters; to highlight several exemplary federal, state, tribal and local programs that assess coastal ecological and water quality conditions. | 2001 | Varies (1-4 yr. cycle) | http://www.epa.gov/owow/oceans/nccr/2005/Chap8_AK_HI_islands.pdf |
| | VI Beach Water Quality Monitoring Program | DPNR-DEP | Evaluate nearshore water quality; notify public of possible human health impact of pathogens | 2004 | Weekly | http://dpnr.gov.vi/dep/ |
| | UVI CMES Sediment Monitoring Program | UVI-CMES | Examine relationship between sedimentation rates, distance from shore and coral condition | 2004 | Monthly (with gaps) | |
| **Benthic Habitats** | **DPNR and U.S. EPA Coral Bioassessment/ Biocriteria Monitoring (Fore et al., 2006 a and 2006b; Fisher, 2007)** | **EPA, DPNR-DEP** | **To evaluate a stony coral bioassessment protocol for application to biocriteria development in the USVI** | **2006** | **Twice/year (STX), one mission proposed for STT/STJ** | http://epa.gov/bioindicators/coral/coral_biocriteria.html |
| | Characterization of benthic habitats in the VINP and BIRNM | CCMA-BB | To spatially characterize and monitor composition of benthic habitats to help quanitfy fish-habitat interactions and support management | 2001 | Annual (STJ); biannual (STX) | http://www8.nos.noaa.gov/biogeo_public/query_main.aspx |
| | NOAA Benthic Mapping and Characterization | CCMA-BB | To characterize and map mid- and deep-water habitats in the USVI | 2004 | Annual | http://ccma.nos.noaa.gov/products/biogeography/usvi_nps/overview.html |
| | **NOAA Coral Bleaching Assessment (Clark et al., in review)** | **CCMA-BB, NPS SFCN** | **To assess spatial patterns in the extent and severity of bleaching in and around BIRNM, St. Croix** | **2005** | **One time** | http://coralreefwatch.noaa.gov/caribbean2005/ |
| | **NOAA/NMFS USVI *Acropora* Mapping Project** | **NOAA NMFS** | **To develop a spatial database on the distriution of *A. palmata* in the U.S. Caribbean** | **2006** | **Ongoing** | |
| | **NPS Assessment of Bleaching Impacts to *A. palmata* at BIRNM (Lundgren and Hillis-Starr, in revision)** | **NPS** | **To monitor the status of *A. palmata* in the 3 major BIRNM habitat types** | **2005** | **Originally, 1 month; now 6 month** | **Program will be supplanted by a more comprehensive assessment of *A. palmata* at BIRNM and EEMP** |
| | Coral Monitoring Program for VINP and VICRNM (Miller et al. 2003 and 2006; Rogers et al., in press). | NPS and USGS | To monitor disease and cover of corals within the Virgin Islands National Park (VINP) and Virgin Islands Coral Reef National Monuments (VICRNM) | 1997 | Every three months | |
| | Elkhorn Coral Monitoring Project (Rogers and Muller, In prep.) | NPS and USGS | To map and monitor changes in the abundance and condition of Acropora palmata colonies | | | |
| | **TNC, UVI-CDC *Acropora palmata* Mapping** | **TNC, UVI-CDC** | **To map the spatial distribution of size classes and health status of *A. palmata* colonies at selected sites** | **2006** | **One time** | |
| | Territorial Coral Reef Monitoring Program (Nemeth et al., 2003; 2004b; 2004c; 2005) | UVI-CMES, DPNR-CZM | To examine long-term trends in coral reef condition including benthic cover and coral health assessments. | 2000 | Annual and during significant events | |

| Ecosystem Component | Data Set | Source Agency | Objectives | Start Date | Frequency | Program Information |
|---|---|---|---|---|---|---|
| **Associated Biological Communities** | NOAA CCMA-BB Monitoring of Temporal Trends in Fish Communities of the USVI | CCMA-BB | To spatially characterize and monitor benthic composition for use in quantifying fish-habitat interactions to support management | 2001 | STX 2x/ year; STJ annually | http://www8.nos.noaa.gov/biogeo_public/query_main.aspx |
| | **NOAA CCMA-BB Fish Tagging Study (Friedlander and Monaco, 2007)** | **CCMA-BB** | **To understand and quantify movement patterns and habitat affinities of USVI reef fishes** | **2006** | **Ongoing** | |
| | SEAMAP-C fisheries-independent monitoring (Gomez, 2000; Tobias et al., 2002; Tobias, 2005; Whiteman, 2005) | DPNR-DFW | To collect information on densities of queen conch and habitat in shallow back-reef embayments | 1998 | Variable | http://www.vifishandwildlife.com/Fisheries/FisheriesReports/ |
| | UVI-CMES Monitoring of Spawning Aggregations (Nemeth, 2005; Nemeth et. al., 2004a; 2006a; 2007; Kadison et al., 2007) | UVI-CMES | Assess status of grouper and snapper spawning aggregations and evaluate effects of MPA's on spawning population | 1999 | Annual | |
| | TCRMP - Fish Assessments (Nemeth et al., 2004b; 2005; 2006b) | UVI-CMES, DPNR-DFW, DPNR-CZM | To examine long-term trends in reef fish populations | 2000 | Annual | |
| | **Assessment and Monitoring of Spiny Lobster Populations at BIRNM (Hunt and Cox, 2005)** | **NPS and FFWC** | **To determine the status and trends of *P. Argus* inside BIRNM and in adjcent fisheries** | **2004** | **Annual** | |

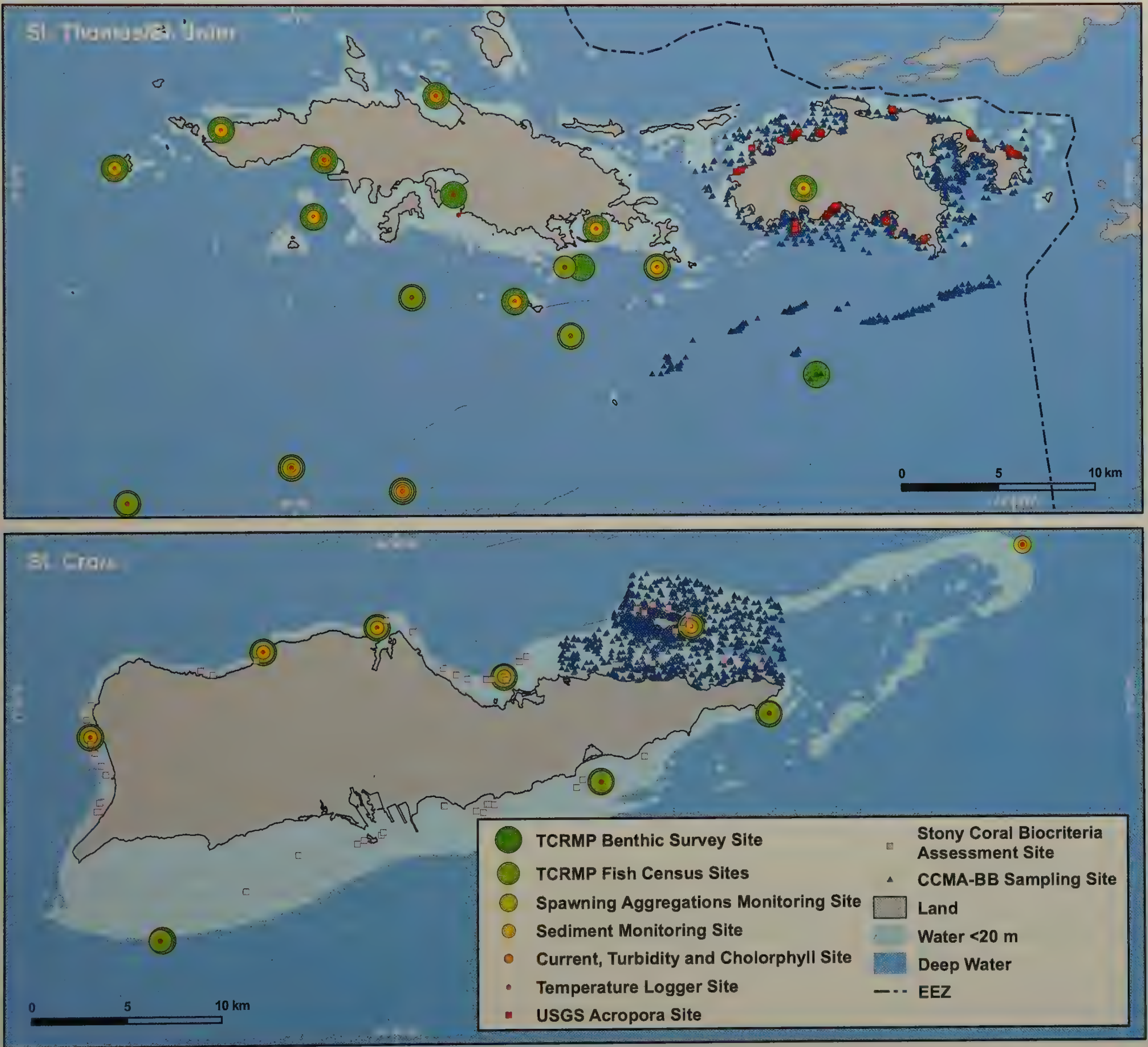

St. Thomas/St. John
0
5
10 km
St. Croix
0
5
10 km
TCRMP Benthic Survey Site
TCRMP Fish Census Sites
Spawning Aggregations Monitoring Site
Sediment Monitoring Site
Current, Turbidity and Cholorphyll Site
Temperature Logger Site
USGS Acropora Site
Stony Coral Biocriteria Assessment Site
CCMA-BB Sampling Site
Land
Water <20 m
Deep Water
EEZ

Figure 2.13. Locations of monitoring and research efforts occurring in the USVI between 2004 and 2007. Map: K. Buja.

## WATER QUALITY AND OCEANOGRAPHIC CONDITIONS

### USVI DPNR-DEP Water Quality Monitoring/EPA Water Quality Assessments

The previous USVI State of the Reef report (Jeffrey et al., 2005) focused on water quality data collected by DPNR-DEP and NPS/USGS prior to the year 2000. DPNR-DEP's Ambient Monitoring Program is presently the primary mechanism for monitoring the territory's coastal water quality. The methods employed and parameters monitored by DPNR-DEP as part of the Ambient Monitoring Program are the same as were detailed by Jeffrey et al. (2005). The program was recently expanded to include deep offshore sites, and now a total of 167 sites (77 around St. Croix, 66 around St. Thomas and 24 around St. John) are sampled on a quarterly basis. DPNR-DEP also implements the VI Beach Water Quality Monitoring Program. Water samples are collected weekly at 43 beaches throughout the territory and processed for *Enterococci*; data from this program is used in conjunction with Ambient Monitoring Program data to issue public advisories on the status of waters at popular beaches. Every two years, the U.S. Environmental Protection Agency (EPA) requires DPNR-DEP to submit reports on the territory's water quality under Section 305(b) of the Clean Water Act. DPNR-DEP is also required, under Section 303(d) of the Clean Water Act, to submit a separate prioritized list of waters that are impaired and implement pollution controls such as the development of Total Maximum Daily Loads (TMDL). Data collected by DPNR-DEP to fulfill reporting requirements are now being integrated into one report, an Integrated Water Quality Monitoring and Assessment Report that is submitted to the EPA. This integrated report describes the condition of territorial waters and whether the waters meet standards pursuant to Section 305(b), identifies impaired waters and those in need of TMDL development pursuant to Section 303(d) and identifies waters being removed from the 303(d) list because they are now in compliance.

#### *Results and Discussion*

Results from DPNR-DEP's water quality monitoring programs show that while water quality in the USVI is generally good, it continues to decline. In 2006 DPNR-DEP (2006) included 69 areas are on the 303(d) list of impaired waters up from 50 on the 2004 list (DPNR-DEP, 2004). In conjunction with EPA, DPNR-DEP has created a schedule for the creation of TMDLs for these water bodies. To date, 14 water bodies have established TMDLs, and watershed restoration action strategies continued for eight water bodies in 2007 and 2008.

Surface waters in the USVI continue to be affected by increasing point and nonpoint sources of pollution. Nonpoint sources, such as runoff from construction sites and unpaved roads, failure of best management practices on construction sites, failure of onsite disposal systems, failing septic systems and the direct discharge of waste overboard from vessels cause a majority of the surface water contamination problems in the territory. Primary problems affecting nearshore waters as a result of these discharges are sedimentation and bacterial contamination. Regulation of such activities is difficult and largely voluntary. Sewage bypasses from the municipal sewage system and wastewater effluent from both permitted and illegal discharges continue as well.

Several efforts have been made to remedy these problems or mitigate their effects during this reporting period. DPNR-DEP is currently revising its water quality standards which were last successfully revised in 2004. DPNR-DEP is also developing stormwater regulations to be implemented through a stormwater control program for the territory. The Storm Water Program will enhance DPNR-DEP's ability to regulate and enforce poorly maintained construction and industrial sites. DPNR-DEP has also developed a Clean Marina Program in an effort to mitigate discharges from these facilities. In an effort to address the troubled municipal sewage system, the VI Government created a new agency, the VI Waste Management Authority to oversee the treatment facilities and local landfills. Additionally, treatment plants and pump station equipment was repaired or replaced in St. Croix, St. Thomas and St. John.

### UVI–CMES Sediment Monitoring Program

Sedimentation rates on 10 St. Thomas and St. John reefs (five near-shore, four mid-shelf and one offshore) have been determined using passive collectors since December 2004 as part of the coral reef monitoring program conducted by CMES with funding from DPNR-DEP. Sediment traps consist of PVC tubing, 20 x 5 cm internal diameter, that has been driven into non-living portions of reef and placed so the top of the traps sit 0.5 m above the substrate. Collected sediments are rinsed twice with dionozied water to remove salts and dried at 70 °C. Dried sediments are sieved and weighed to the nearest 0.001 g. Sediments that are < 0.075 mm are considered terrigenous in origin and are used to calculate the sedimentation rate. Rate of sediment accumulation (g/cm$^2$/day) is determined by dividing the weight of dried sediment by the area of the trap and then by soak time. Full methods are presented in Nemeth et al. (2004).

#### *Results and Discussion*

Results showed a clear and significant onshore-offshore sedimentation gradient; nearshore sedimentation rates were six times greater than at mid-shelf reefs, and nearly 50 times greater than at offshore reefs. This clear stress gradient suggests that the potential impact from sedimentation on nearshore reefs is higher than on mid-shelf and offshore reefs. A similar onshore to offshore gradient was also found in a number of coral health indices, including bleaching prevalence and percentage of old mortality, indicating that sediment deposition may be, in part, adversely affecting coral condition. Additionally, very strong (> 90%) and significant correlations were found between sedimentation rates during the rainiest months and disease prevalence, as well as the proportion of old mortality on nearshore coral reefs. These results suggest that the impact of heavy seasonal sediment loads can be significant on the nearshore environment.

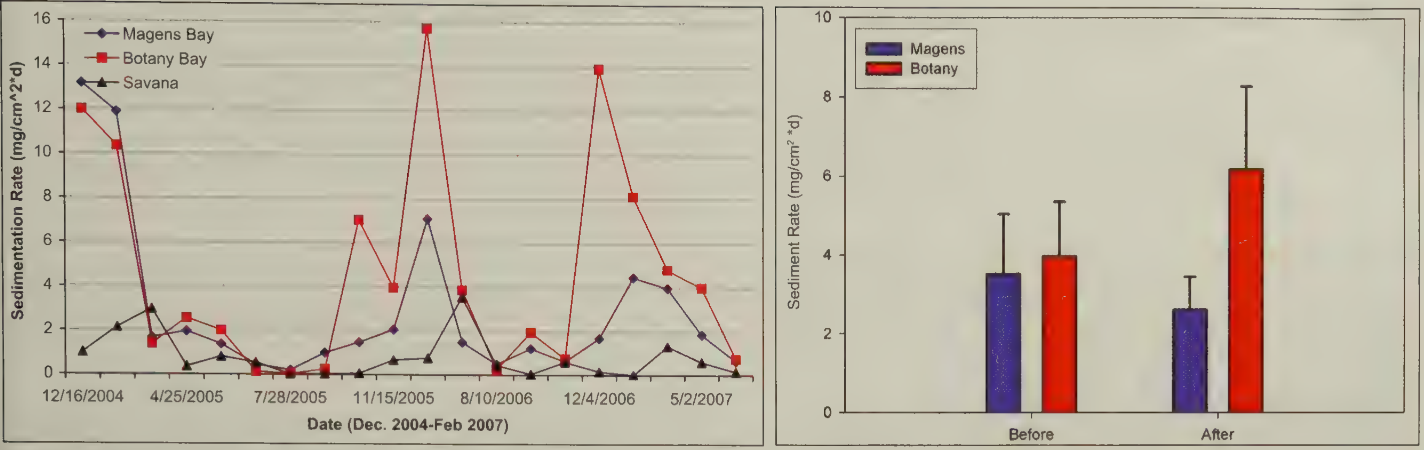


*Figure 2.14. Mean sedimentation rate for each sampling period on north side St. Thomas sites (left). Mean sedimentation rate at Magens Bay and Botany Bay (right) before (December 2004-October 2005) and after (November 2005-March 2007) development at Botany Bay. Source: J. Blondeau, UVI-CMES.*

Development activities in Botany Bay beginning in October 2005 resulted in a non-significant, yet marked increase in sedimentation rates (Figure 2.14). Interestingly, though, sedimentation rates at Botany Bay were relatively high, as compared to Magens Bay, prior to any development, which is somewhat counterintuitive given that the level of development in the Magens Bay watershed is much higher. This apparent disconnect between runoff potential (e.g., watershed characteristics including slope, soil type and land use) and sedimentation rate underscores the complexity of sediment transport within a watershed and suggests that sediment deposition onto nearshore reefs is driven by other means, likely oceanographic. High resolution, local oceanographic current models developed by UVI and the University of Miami's Rosenstiel School of Marine and Atmospheric Science show that the general westward moving currents for St. Thomas and St. John, tidal and wave energy, as well as the formation of localized eddies are all driving factors in the deposition of terrestrial sediments. Results of this sediment monitoring program suggest that the delivery of terrigenous sediment is a function of watershed characteristics, but the deposition of land-based soils onto reefs is driven by oceanographic mechanisms and, to some degree, is affecting nearshore coral condition.

### *NPS Water Temperature Monitoring at BIRNM*

Water temperature data from BIRNM has been recorded since 1991. Although data gaps exist in many years, partial data exists for every year. Initially, Ryan RTM2000 temperature loggers were placed at the base of the eastern fore reef of Buck Island adjacent to the Underwater Trail at approximately ten meters depth. In 2003, NPS switched to HOBO temperature loggers, and an additional site was established on the back reef approximately midway along the north shore at 2 m depth.

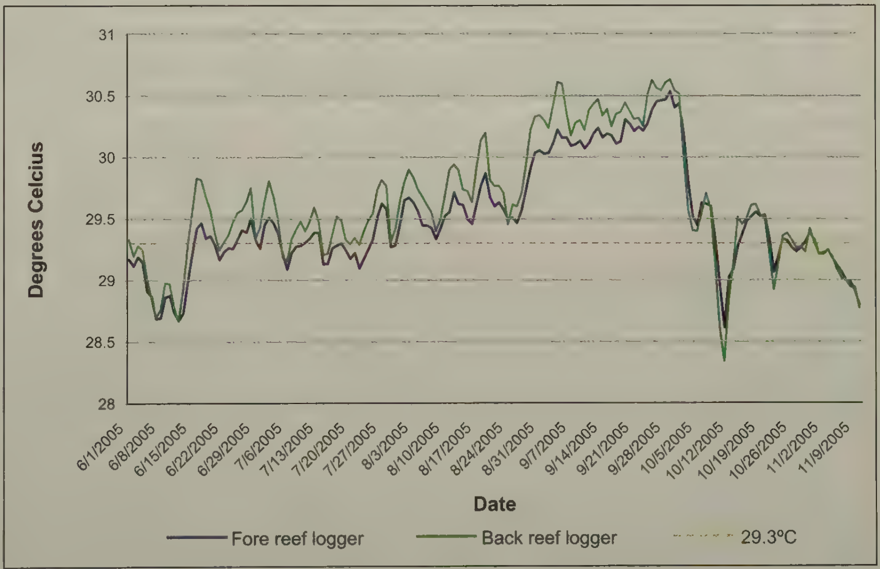


*Figure 2.15. Subsurface water temperatures at BIRNM during the 2005 mass bleaching event. Both loggers are located adjacent to Buck Island on the barrier reef. The back reef logger is located at 2.5 m depth on the back reef just north of Buck Island. The fore reef logger is located at 10 meters depth on the easternmost fore reef. Source: adapted from Lundgren and Hillis-Starr (in revision).*

*Results and Discussion*

The long-term data set from the fore reef of BIRNM displays a clear annual cycle. Temperatures are generally lowest in February and highest in September, and tend to fluctuate between 26-29°C. There was no clear trend showing that water temperatures have increased since 1991; however, the mass bleaching event in 2005 produced the highest temperatures recorded since 1991. It has been noted that at BIRNM, temperatures regularly exceed the theoretical "bleaching threshold" without causing bleaching. Duration above the bleaching threshold, in addition to temperature intensity, appear to be synergistic factors which combine to influence bleaching (Lundgren and Hillis-Starr, in revision). From data collected over the last four years, temperatures on the back reef appear to fluctuate more (Figure 2.15), getting slightly warmer than the fore reef and heating up more rapidly. However, back reef temperatures also cool down more quickly. Average temperature exceeded the bleaching threshold of 29.3°C for 85 days on the back reef and for 73 days on the fore reef during the bleaching period. Water temperature peaked at over 2°C above the long-term average maximum on September 29, 2005 at the back reef location.

## BENTHIC HABITATS

Jeffrey et al. (2005) focused on five benthic data sets from various federal and territorial monitoring programs. Four of these five programs have continued and five new coral monitoring projects were launched during this reporting cycle. New projects include those aimed at describing populations of threatened *Acropora* corals, characterizing the scope and effects of the 2005 coral bleaching event and a feasibility study for the development of stony coral biocriteria as a water quality regulatory tool. Data collection methods did not change significantly between reporting periods for the ongoing monitoring programs.

### *NPS and USGS Coral Disease and Benthic Cover Abundance Monitoring*

Long-term monitoring of coral disease, abundance and benthic cover continues to be conducted by the NPS SFCN's Inventory and Monitoring Program around St. John and BIRNM in St. Croix. Methods employed in these monitoring programs have been detailed in Miller et al. (2003), Jeffrey et al. (2005) and Rogers et al. (in press).

#### *Results and Discussion*

Information provided in this section has been summarized from Rogers et al. (in press); for more detailed descriptions, please see that publication and Miller et al. (2006). During the 2005 bleaching event more than 90% of coral cover bleached at long-term sites in St. John. Monitoring during and after the event showed that in addition to mortality associated with bleaching, corals also suffered significant losses due to a post-bleaching disease outbreak. While losses of coral cover at the St. John and BIRNM sites occurred from bleaching, the overwhelming mortality documented was attributed to white plague. In 12 months, loss of coral cover at the seven SFCN USVI monitoring sites ranged from 34.1% to 61.8% (NPS, unpub. data; Figure 2.16). *Montastraea annularis* species complex continues to be the dominant coral at these sites, but its abundance relative to other species declined by approximately 7% as a result of this event. Other species such as *Colpophyllia natans* declined in relative abundance, and *Agaricia agaricites* declined in both relative abundance and total cover. Data also showed that disease incidence was more extensive after the bleaching event than prior to the onset of bleaching. Additionally, through side by side comparison of video footage, it was determined that the larger colonies of major framework-building species were more severely bleached. Recovery from the bleaching was variable. *M. annularis* complex showed significant recovery followed by disease impacts, while other species appeared to die as a result of the bleaching event itself. Across the monitoring sites, 6,061 disease lesions were noted on 23 species of coral between September 2005 and July 2006. While several diseases were noted, 99% of the lesions and loss of coral cover was due to white plague. At the long-term (1997-current) coral disease monitoring sites in St. John, a particularly severe outbreak of a coral disease presenting signs consistent with white plague was noted in August of 2005. Significant losses of coral cover have been documented over the term of the study.

### *Territorial Coral Reef Monitoring Program (TCRMP)—Benthic Cover and Coral Health Assessments*

Monitoring of benthic composition and coral health by UVI-CMES as reported in Jeffrey et al., (2005) continued during this reporting cycle. UVI-CMES researchers used digital videography along belt transects to monitor benthic cover at permanent and rapid assessment sites in St. Croix and St. Thomas (Nemeth, 2005). Digital video and diver surveys were used to quantify coral diversity; the percent cover of corals, algae and other organisms; and incidence of coral bleaching and disease at eight permanent sites around the island of St. Croix and 16 permanent sites around the island of St. Thomas and St. John. Detailed video sampling and coral health assessment methods are discussed in Nemeth et al. (2005).

#### *Results and Discussion*

Extensive monitoring of coral reef sites outside NPS boundaries has shown a correspondence between nearshore stressors (e.g., sedimentation and other forms of terrestrial runoff) and coral degradation and disease for a gradient in St. Thomas and St. John (Smith et al., in review). Prior to the mass bleaching and mortality event of 2005, the disease and stress indicators, bleaching, and old mortality, were all significantly higher, and coral cover lower, on nearshore coral reefs than at offshore locations (i.e., midshelf cays, deep reefs, and deep shelf edge sites; Figure 2.17). On St. Thomas and St. John nearshore reefs there was also a high correlation (+90%) between sedimentation in the rainy season and prevalence of coral disease and partial mortality. In addition, at nearshore sites in St. Croix, St. Thomas and St. John monitored between 2001 and 2005, there was no significant loss or increase of coral cover, but there was an increase in cover of ephemeral "weedy" coral species and a decrease in ecologically important crustose coralline algae (Figures 2.18 and 2.19). These findings highlight the impairment of nearshore coral reefs relative to reefs buffered from terrestrial stressors, and suggest that current management of run-off in the USVI has been insufficient to stem degradation.

The 2005 mass coral bleaching event had widespread and dramatic effects on the abundance and composition of coral reefs in locations monitored by the TCRMP (Smith et al., unpub. data). The unprecedented warm SSTs in September and October of 2005 caused an average bleaching of 57% of coral cover, and half of all bleached corals had severe bleaching (stark white appearance) over 90% or more of the colony. Stress caused by bleaching resulted in an initial loss of 4% of coral cover during the bleaching event; however, after the warm water subsided in early to mid-2006 an average prevalence of white plague not seen in the previous five years of monitoring (5% versus 0.5%, respectively) precipitated a large loss of coral cover that equaled 40% by 2007 (Figure 2.20). Ecologically important framework-building star corals of the *M. annularis* complex were hardest hit, with some sites losing >70% of coral cover in this genera. Locations that were most affected tended to be shallower than 30 m, previously had high coral cover that could have favored the spread of pathogens, and were subject to other stressors, such as high fishing pressure and/or proximity to industrial effluents. Deeper shelf edge sites that did not bleach extensively, likely due to lower UV penetration and a moderating thermal oceanographic environment, were not immune to the coral disease outbreak that produced large losses in live coral cover (Figure 2.20).

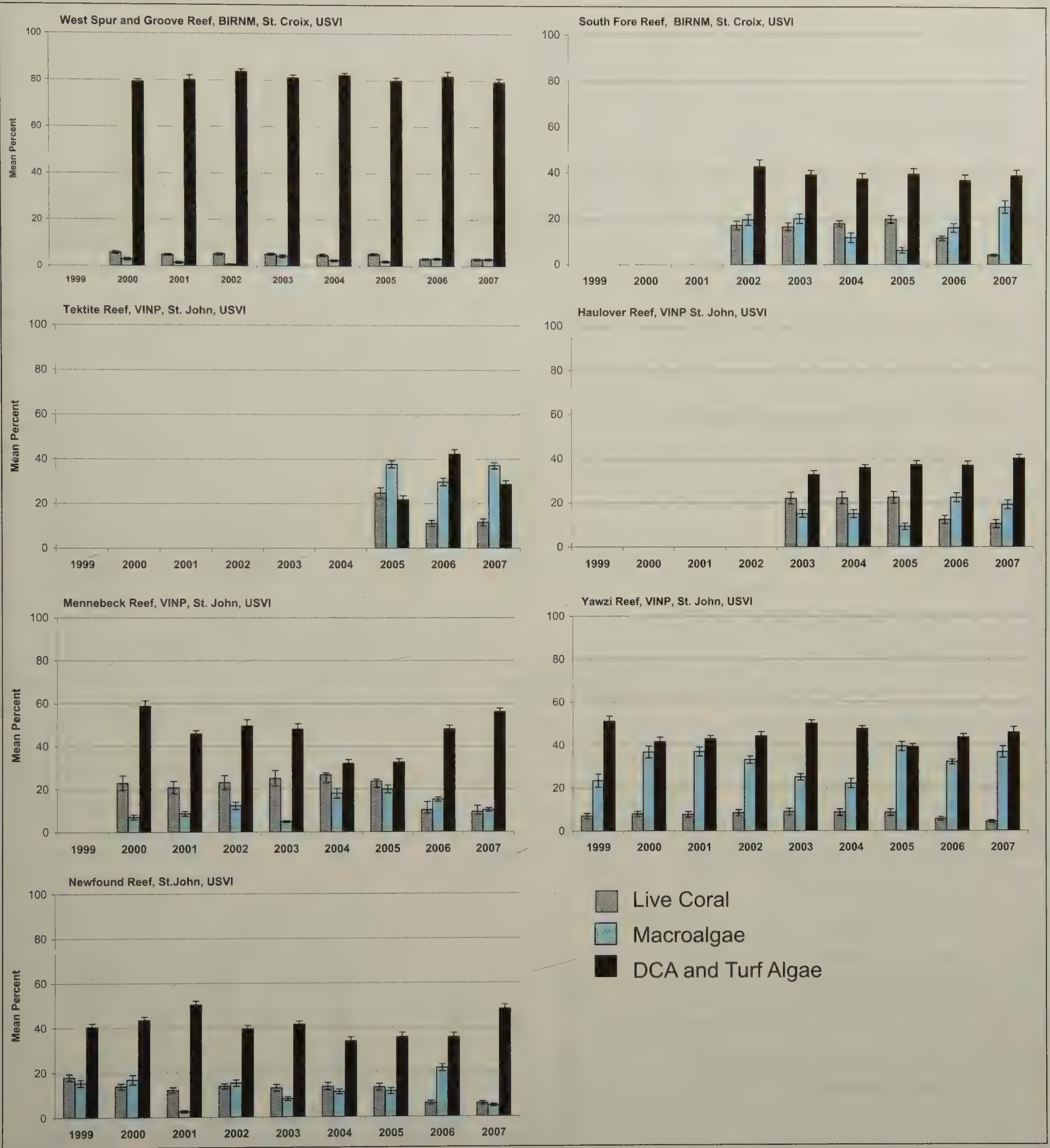


*Figure 2.16. Mean percent coral cover (with standard error bars) at seven sites in the USVI. Protocol uses 20 randomly selected video transects per site. Between 2005 and 2006 coral cover declined by half in several locations. Source: NPS unpub. data, compiled by J. Miller, NPS.*

### *NPS, USGS and UVI-CMES Elkhorn Coral (*Acropora palmata*) Monitoring*

Jeffrey et al. (2005) included preliminary results from this monitoring project. Since then, USGS, NPS and UVI have completed extensive surveys of *A. palmata* around St. John, with one-time assessments at 11 reefs (July 2004–July 2005) and monthly monitoring at reefs in Saltpond and Trunk Bay (July 2005–August 2006), Hawksnest (May 2004 to date) and Haulover (February 2003 to date; Rogers, 2005; Rogers et al., 2005; Rogers et al., 2006; Muller et al., 2007). The geographic coordinates of the perimeter of each monitoring site and the locations of sampled elkhorn colonies are mapped onto geo-referenced aerial photographs. Data are recorded on the depth, three-dimensional size of colonies, type of substrate, percent cover of live and dead coral, presence/absence of specific diseases and lesions, and counts of damselfish territories and coral predators such as snails (*Coralliophila abbreviata* and *C. caribaea)* and fireworms (*Hermodice* spp.).

*Results and Discussion*

During the 2005 severe bleaching event (Eakin, 2007), elkhorn coral bleached for the first time on record in the USVI. Of 460 *A. palmata* colonies being monitored at four locations in VINP (Hawksnest, Haulover, Saltpond and Trunk Bays), 50% (±9.6%) showed signs of bleaching. Of these, 36% (±7.4%) experienced partial mortality and 15% (±8.5%) suffered complete mortality (McCreedy et al., 2006). Mortality rates of monitored *A. palmata* increased during 2005 at all four sites, but were not always directly related to bleaching. Isolated incidences of disease as well as bleaching contributed to the rise in mortality rates. Unlike deeper reefs dominated by *Montastraea* spp. (Miller et al., 2006), bleaching was not followed by severe outbreaks of disease except at one site, Hawksnest Bay. Here, a combination of disease and bleaching caused more mortality than all other stressors combined. Surviving colonies regained normal color by February 2006.

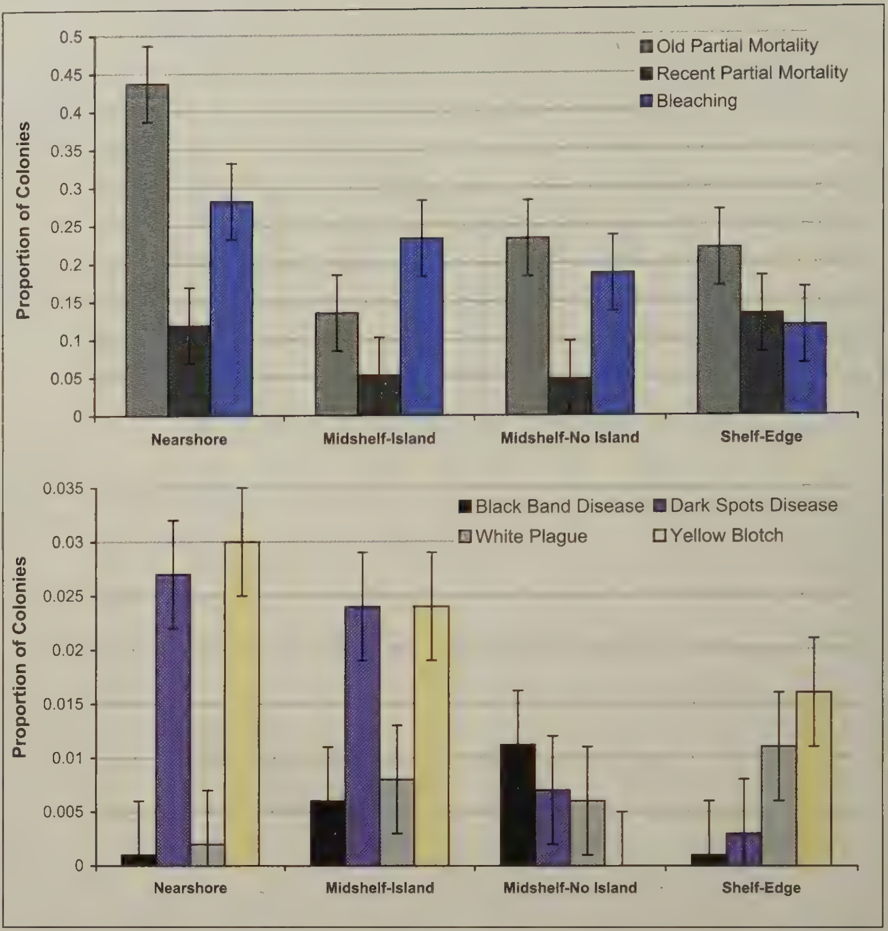


*Figure 2.17. The proportion of colonies (prevalence) displaying old and recent partial mortality and bleaching at 16 sites from nearshore, midshelf and shelf-edge sites near St. Thomas and St. John (top) and the proportion of colonies with recognized coral disease (bottom). Both panels show a general increase of stress indicators and some diseases in nearshore environments. Source: T. Smith, UVI-CMES.*

From May 2004 through December 2006, disease affected 87% of monitored colonies at Hawksnest (n=60 at the start of the study). Disease signs observed were consistent with white pox. Over 94% of the lesions that were completely surrounded by live tissue showed signs of healing (Muller, 2007). In 2005 (the year of the bleaching event) disease prevalence and the rate of change in prevalence showed a positive linear relationship with water temperature (Muller et al., 2008). In addition, colonies that bleached had greater area of disease-associated mortality than those that showed no sign of thermal stress, indicating disease severity is related to host-susceptibility (Muller et al., 2008; Figure 2.21).

Over a period of 50 months at Haulover (through April 2007), 88% of the elkhorn colonies exhibited disease, including white pox (87%), white band (15%) and unknown disease (9%). Some colonies had more than one disease at a time. Just over half of the colonies were damaged physically, from snorkelers, fishing line and storm waves.

When bleaching was first observed at Haulover in September 2005, 54 colonies of the initial 69 remained. Of the 43% of these that bleached, only one appeared to die directly from bleaching while 11 suffered some mortality. Thirteen colonies regained normal coloration and recovered after bleaching. More colonies died during the bleaching event than during the rest of the study. Seawater temperature in Haulover ranged from

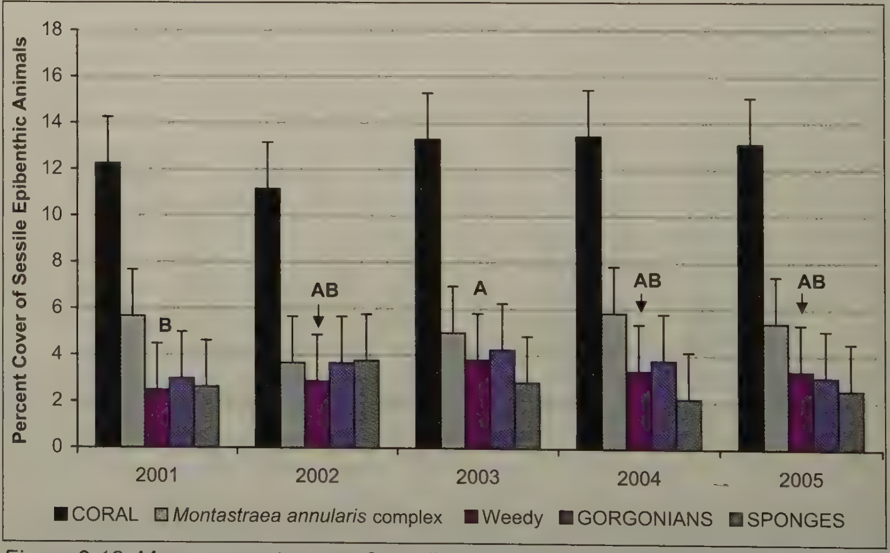


*Figure 2.18. Mean percent cover of sessile epibenthic animals at nine sites sampled annually from 2001 to 2005 on St. Croix, St. Thomas, and St. John. Weedy=a complex of fast recruiting disturbance tolerant coral species (*Agaricia agaricites, Diploria strigosa, Porites astreoides,* and* Siderastrea radians*) that may indicate stressful or disturbed environments. Letters above means indicate significant differences between years. Source: T. Smith, UVI-CMES.*

24.9°C (February 9, 2005) to 31.4°C (September 12, 2005). In 2005, the maximum daily temperature exceeded 30°C on 65 days, including 44 consecutive days. The highest temperatures occurred from August through October 2005. Bleaching was apparent from September 2005 through January 2006, with a peak in September, when over 40% of the colonies were bleached. White band disease, thought to have been responsible for extensive mortality of *A. palmata* in the USVI in the late 1970s and 1980s, was only seen on a few colonies on St. John reefs in the last four years. White pox was far more common.

### Assessment of Bleaching Impacts to Acropora palmata at BIRNM

At BIRNM, *A. palmata* experienced extensive bleaching in 2005. NPS staff quantified the extent of the bleaching and subsequent mortality. In general, *A. palmata* colonies located in the back reef bleached earlier and suffered greater tissue loss than those on the fore reef and reef shelf. Colonies on the fore reef ultimately suffered mortality comparable to the back reef, but the reef shelf experienced half this amount.

*Methods*

The impact of the bleaching event on *A. palmata* colonies at BIRNM was measured by monitoring 44 colonies at three sites located in back reef, fore reef, and reef shelf habitat types where *A. palmata* is found. Although *A. palmata* is present on shallow haystack features and on the barrier reef surrounding Buck Island, the majority of *A. palmata* habitat at BIRNM is found on the northern reef shelf or north bar, which is deeper habitat (5-10 m) north of Buck Island. Two of the three sites were located on Buck Island's barrier reef, in the back reef near the Underwater Trail and on the south fore reef; the third site was located on the north bar. Colonies were monitored monthly before, during, and after the bleaching event (beginning in March 2005) and therefore provided a complete record of bleaching impacts. Colonies were photographed preferentially from the planar view, but from a consistent oblique angle in shallow water situations.

*Results and Discussion*

Among the 44 colonies examined, 36 (82%) experienced bleaching. Maximum bleaching for all sites occurred in November 2005. At the back reef site 45.8% of live tissue was bleached, while on the south fore reef 79.8% of live tissue was bleached. At the north bar, outside the barrier reef, 64.1% of the live tissue was bleached. Back reef colonies were impacted before south fore reef and north bar colonies. In August 2005, the back reef site experienced bleaching levels of 25%,

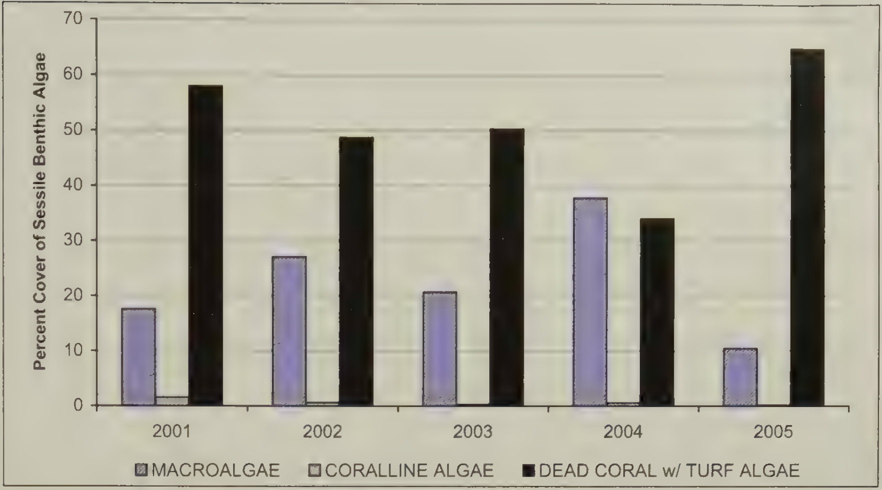


*Figure 2.19. Percent cover of sessile benthic algae at 9 sites sampled annually from 2001-2005 on St. Croix, St. Thomas, and St. John. Source: T. Smith, UVI-CMES.*

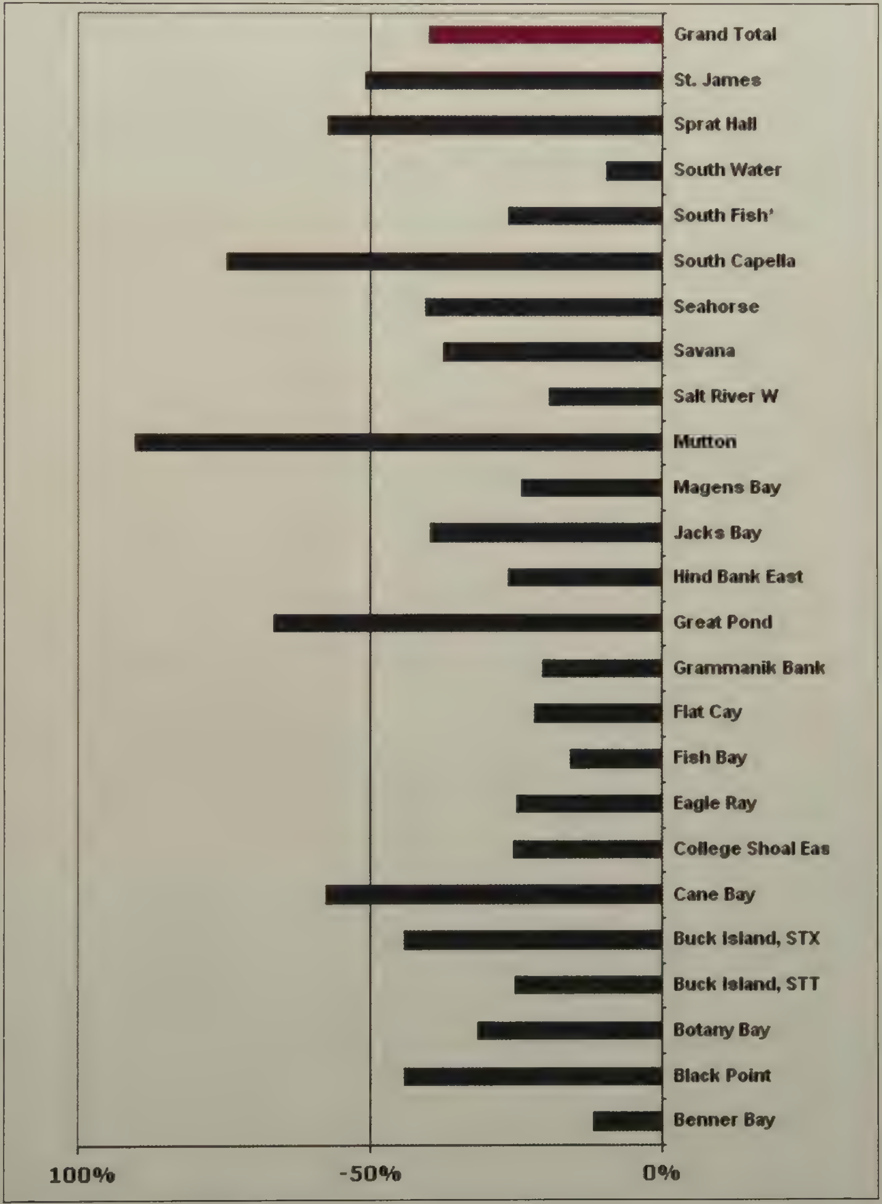


*Figure 2.20. The loss of coral cover at 24 territorial coral reef monitoring sites in the USVI between early 2005 (pre-bleaching) and mid to late 2006 (post-bleaching) as the result of the bleaching event and subsequent coral disease outbreak. The largest loss of coral cover were typically seen in high coral cover locations dominated by the important reef-building* M. annularis *complex. Source: T. Smith, UVI-CMES.*

whereas the fore reef site experienced only 11% bleaching. Most of the sea water temperature measurements exceeding 30°C were recorded in September, with the highest (30.6°C) on September 29, 2005 on the back reef.

Mortality, like bleaching, was higher in the back reef than at the north bar, and the back reef exhibited greater mortality sooner. The back reef experienced the highest average tissue loss during the event (66.4%), followed by the south fore reef (58.1%) and the north bar (36.4%; Table 2.2). Overall, out of 44 colonies, only two did not experience any mortality during the bleaching event.

Rapid and severe bleaching and mortality associated with the back reef may be linked to restricted water flow, less wave action, and increased light penetration found in these locations (Nakamura and van Woesik, 2001) in addition to slightly higher water temperatures. Mortality on both the fore reef and back reef was at least double that of the reef shelf. Lastly, mortality may have resulted from undetected disease as well as bleaching. Diseased tissue may have been under-represented, as it can be similar in appearance to bleached tissue (particularly white-band and white pox).

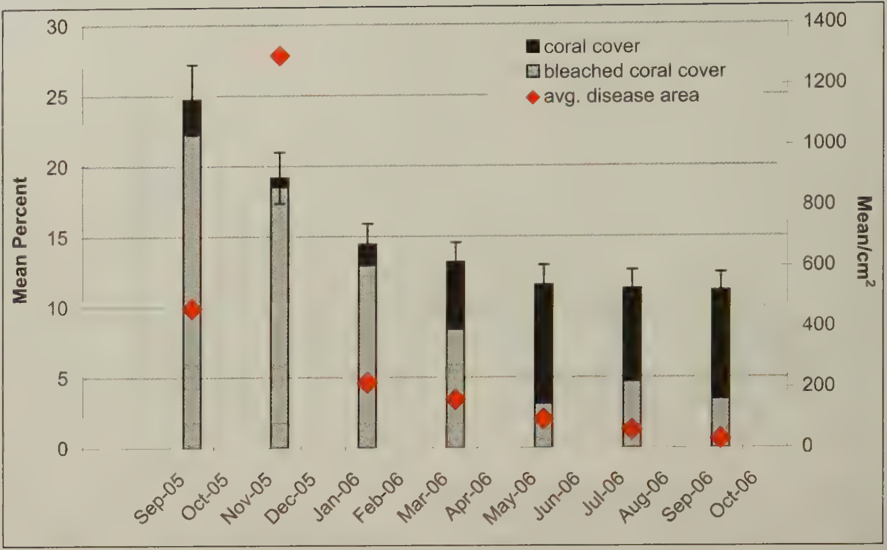


*Figure 2.21. Relationship between disease prevalence and bleaching at Hawksnest Bay, St John, USVI in 2005. Source: adapted from Muller et al., 2008.*

*Table 2.2. Bleaching and mortality assessment of corals at three sites in representative habitats at BIRNM. The north bar (N.Bar) is located on the reef shelf, the south fore reef (SFR) is on shallow fore reef habitat, and the Underwater Trail (UWT) is in the back reef. Source: Lundgren and Hillis-Starr (in revision).*

| | | Assessment AUG 28, 2005 | Mortality AUG-NOV 2005 | Assessment NOV 1, 2005 | Mortality NOV 2005-JAN 2006 | Assessment JAN 26, 2006 | Cumulative MORTALITY |
|---|---|---|---|---|---|---|---|
| **N. Bar** | mean | 0.0 | 9.1 | 64.1 | 27.3 | 2.0 | 36.4 |
| | median | 0.0 | 0.0 | 63.0 | 10.0 | 0.0 | 10.0 |
| | ó | – | 19.3 | 36.7 | 36.7 | 3.6 | 41.4 |
| | óM | – | 5.8 | 11.1 | 11.1 | 1.1 | 12.5 |
| | CI | – | 12.0 | 22.7 | 22.7 | 2.2 | 25.7 |
| **SFR** | mean | 11.2 | 14.3 | 79.8 | 50.0 | 3.2 | 58.1 |
| | median | 0.0 | 0.0 | 92.0 | 57.0 | 0.0 | 77.0 |
| | ó | 25.0 | 30.9 | 34.2 | 37.2 | 6.6 | 39.0 |
| | óM | 6.2 | 7.7 | 9.1 | 10.0 | 1.8 | 9.8 |
| | CI | 12.6 | 15.6 | 18.6 | 20.2 | 3.7 | 19.8 |
| **UWT** | mean | 24.1 | 57.2 | 45.8 | 17.4 | 0.0 | 66.4 |
| | median | 0.0 | 60.0 | 40.0 | 15.0 | 0.0 | 85.0 |
| | ó | 33.7 | 39.4 | 32.0 | 15.4 | – | 36.0 |
| | óM | 8.2 | 9.6 | 10.7 | 5.1 | – | 8.7 |
| | CI | 17.1 | 19.9 | 22.2 | 10.7 | – | 17.7 |

### *The Nature Conservancy, UVI–Conservation Data Center Elkhorn Coral (Acropora palmata) Mapping*

In October 2006, The Nature Conservancy (TNC) and the UVI Conservation Data Center (UVI-CDC) implemented a joint project to map the spatial distribution and status of *A. palmata* populations in priority coastal areas around St. Thomas and St. Croix. This project was designed to compliment USGS, NPS and UVI monitoring of *Acropora* in St. John using slightly modified data collection methods to ensure accuracy when transferring the data sets into a spatial context. Eight survey sites around each island were identified through a process of combining historical range data and previous studies with extensive site reconnaissance. The geographic coordinates and a non-standardized photograph of each sampled *Acropora* colony were taken along with data representing a modified version of the Demographic Monitoring Protocols for Threatened Caribbean Acropora Coral (Williams et al., 2006). Data collected include the size and type of colony, number of associated fragments, percent live coral cover, presence/absence of disease and bleaching, and water depth. Comments on presence/absence of damselfish, snails and fish bites were also recorded for all colonies. Data were entered at each site to allow population data to be taken quickly and downloaded to a comprehensive database.

#### *Results and Discussion*

Using the spatial component of this study in combination with watershed information, studies conducted by UVI-CDC will allow population data to be linked to watershed characteristics and land use, following trends for water quality, sedimentation and nutrient risk assessment and their possible link to deteriorating coral reef conditions. Final products will display the survey results alongside critical land use factors. This work will not establish causation for *Acropora* losses or identify individual factors, but it will help managers understand how land use patterns and development activity, point and nonpoint sources, and watershed characteristics affect the condition of adjacent marine communities.

## NOAA CCMA-BB Assessment of Benthic Composition

The goals and objectives of CCMA-BB's Caribbean Coral Reef Ecosystem Monitoring Project are four fold: 1) to spatially characterize and monitor the distribution, abundance and size of both reef fishes and macroinvertebrates (conch, lobster, *Diadema*); 2) to relate this information to *in situ* data collected on associated benthic composition parameters; 3) to use this information to establish the knowledge base necessary for enacting management decisions in a spatial setting; and 4) to establish the efficacy of those management decisions. All of the data collected by CCMA-BB and local partners are available at http://www8.nos.noaa.gov/biogeo_public/query_main.aspx.

On the island of St. John, monitoring efforts are focused on the waters within and around the VINP and the Virgin Islands Coral Reef National Monument (VICRNM), including the mid-shelf reef. Field missions are based on a collaboration between NOAA, the University of Hawaii, the NPS and USGS. Field missions occur annually and include monitoring of approximately 170 stratified random sampling sites located inside and outside park and monument boundaries, as well as at an offshore deep reef area in waters approximately 30.5 m (100 feet) deep. Information collected thus far has been extensively utilized by participating partner organizations as well as by the USVI DPNR, UVI, OC and others.

On St. Croix, CCMA-BB conducts semi-annual monitoring surveys at approximately 120 stratified random sampling locations within and around the waters of BIRNM and the EEMP. Data has been collected in collaboration with local and regional NPS staff, USVI DPNR, NOAA's Coral Reef Watch Program, the National Aeronautical and Space Administration (NASA) and USGS and has been used by the University of Miami, NOVA Southeastern University, TNC, OC and others.

### *Methods*

The CCMA-BB field methodology consists of two complementary components. The first is a 25 m long belt transect used to quantify fish species size and abundance. Fish data are correlated to fine-scale habitat information to identify spatial patterns in community structure or identify essential fish habitats. The second component involves taking detailed habitat measurements along the same belt transect. These measurements are correlated to the fish data to quantify fish-habitat relationships on a small spatial scale. Survey sites are selected using a stratified random sampling design that incorporates the strata derived from CCMA-BB's nearshore benthic habitat map (Kendall et al., 2001). At each site, fish, macro-invertebrates, water quality and habitat information are quantified following standardized protocols. Detailed methodology for both the fish and benthic habitat surveys are located on line at http://ccma.nos.noaa.gov/ecosystems/coralreef/reef_fish/protocols.html. Between 2001 and 2006, benthic surveys were conducted at 768 reef and hardbottom sites around BIRNM and along the northeastern shore of St. Croix, including within the EEMP. During the same period, 233 surveys were conducted around the island of St. John.

### *Results and Discussion*

Data from the NOAA surveys indicate that reef and hardbottom areas in St. Croix are generally dominated by algae (Figure 2.22). In St. Croix, reefs were comprised of 36.7 ± 1.1% turf algae, 11.4 ± 0.5% macro algae, and 1.8 ± 0.2% crustose coralline algae. In St. Croix, the macroalgae with the highest observed cover were *Dictyota* spp., *Halimeda* spp. and *Sargassum* spp. Reefs in St. Croix also had 4.3 ± 0.5% cyanobacteria and filamentous algae that were morphologically indistinguishable from each other. Live scleractinian coral was low and averaged 5.6 ± 0.5%. Reefs in St. John were comprised of 28.5 ± 1.6% turf, 15.3 ± 1.0% macroalgae and 3.3 ± 0.5% crustose coralline algae (Figure 2.22). In St. John, the most common macroalgae genera observed were *Dictyota* spp., *Halimeda* spp and *Lobophora variegata*. Cyanobacteria and filamentous algae had average cover of 1.5 ± 0.4% on reefs in St. John. Live scleractinian coral cover was low and averaged 5.6 ± 0.5 % in both St. Croix and St. John (Figure 2.22). Gorgonians had higher crown cover in St. John when compared to reef and hardbottom areas in St. Croix ($p<0.0001$). Milleporid (fire) corals and sponges also had higher cover in St. John than in St. Croix ($p<0.0002$).

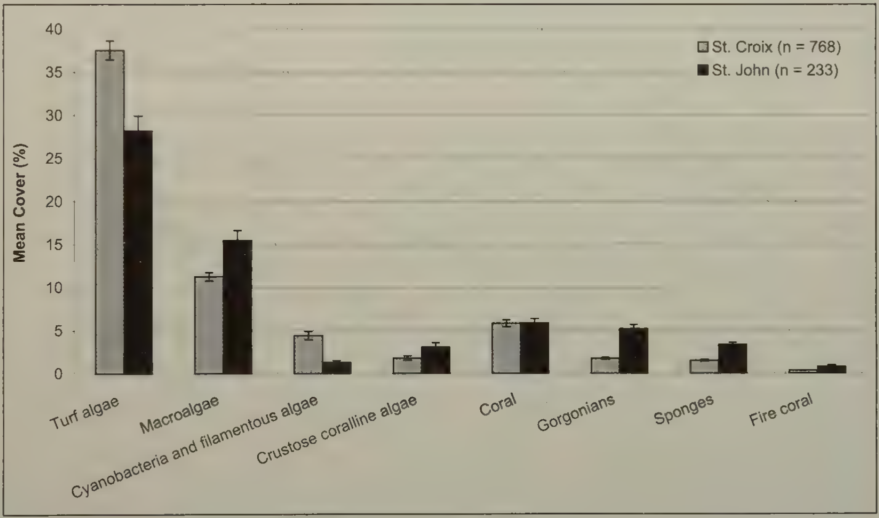


*Figure 2.22. Mean percent cover of benthic organisms on reefs and other hardbottom areas in St. John and St. Croix. Source CCMA-BB.*

Patterns in the cover of benthic organisms were consistent across reef types identified by Kendall et al. (2001), with two algal categories (turf/crustose algae and macroalgae) dominating all six reef types in St. Croix (Figure 2.23). Cyanobacteria and filamentous algae had the highest cover and were most variable on reef rubble and scattered coral and rock sites. The mean percent cover of live scleractinian coral was significantly higher on patch reefs (12.1 ± 1.3%, $p<0.05$) and lowest on reef rubble (2.0 ± 0.8%) and scattered coral and rock sites (3.4 ± 0.7%, Figure 2.23). Gorgonians had the lowest cover on reef rubble sites. The percent cover of sponges and fire corals were similar among the habitat types surveyed.

Patterns in the cover of benthic organisms were also consistent across reef types in St. John, where turf algae and macroalgae were the dominant cover at the sites surveyed (Figure 2.23). Turf algal cover was most variable on reef rubble sites, likely due to variability in the presence of hard structure at rubble sites. In St. John, live coral was significantly higher on linear and patch reef habitats (p<0.05), which had 9.2 ±1.1% and 9.6 ±2.2% of live coral cover, and lower on reef rubble (2.0 ±1.7%) and scattered coral and rock (3.7 ±1.3%).

Live scleractinian coral cover in St. Croix and St. John was comprised mainly of 23 coral genera, but only nine of those had mean cover greater than 0.01% in St. Croix, and 14 had a mean cover greater than 0.01% in St. John (Figure 2.24). The three most abundant corals, *Montastraea* spp., *Porites* spp., and *Diploria* spp., had a mean cover of 1 ±0.09% in St. Croix and 2.4 ±0.34% in St. John. Mean *Porites* cover in St. Croix was 0.9 ±0.06% and 1.1 ±0.15% in St. John. Mean cover of *Diploria* spp. was 1.2 ±0.29% in St. Croix and 0.1 ±0.04% in St. John. Some significant differences in coral composition on reefs and hardbottom areas were observed between St. Croix and St. John. *Montastraea* spp., *Siderastrea* spp., and *Agaricia* spp. had higher average cover in St. John than in St. Croix (p<0.0001). However, *Diploria* spp. and *Acropora* spp. had higher cover in St. Croix than in St. John, (p<0.04). The cover of other coral genera was similar between St. Croix and St. John.

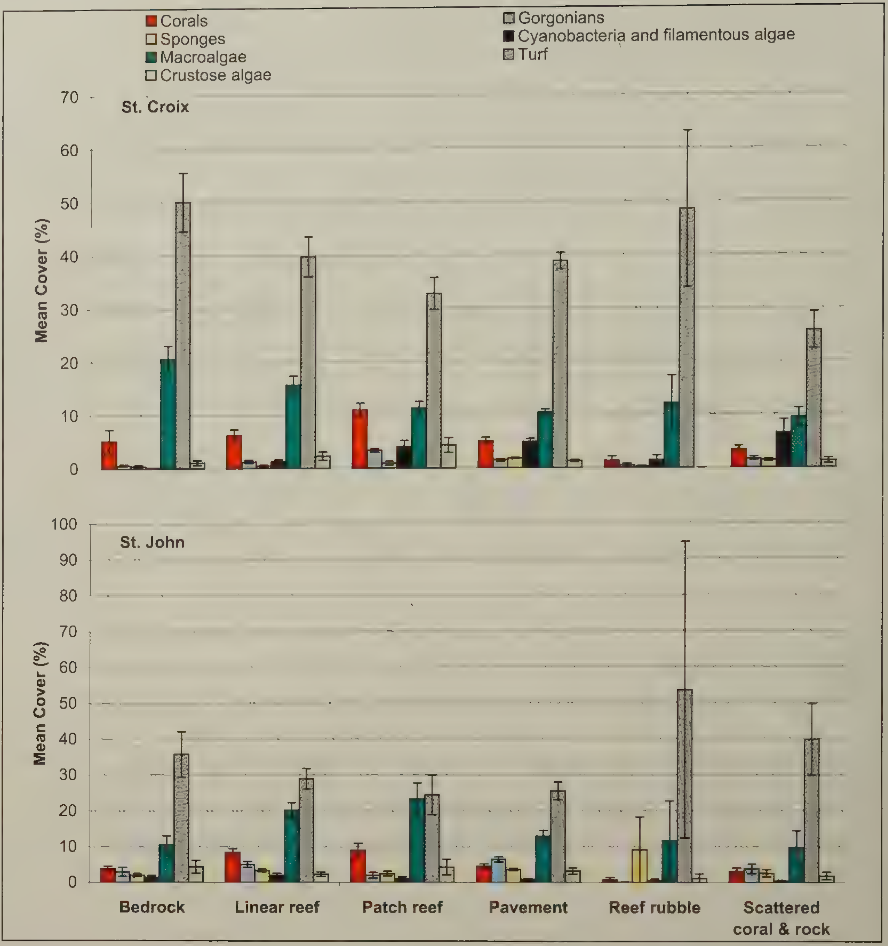


*Figure 2.23. Mean ±SE percent cover of benthic organisms found in different reef habitats in St. John and St. Croix. Source: CCMA-BB.*

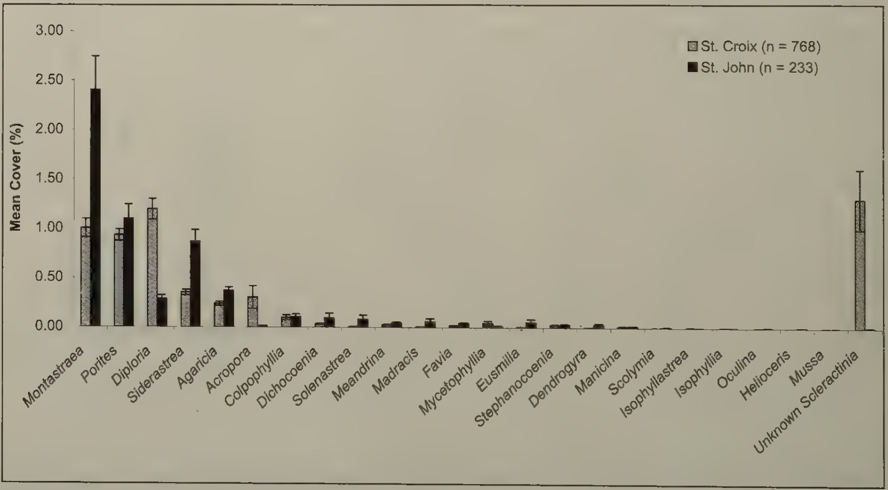


*Figure 2.24. Mean ±SE estimates of percent live cover of coral genera on randomly selected reef sites between 0-28 m in St. John and St. Croix. Source: CCMA-BB.*

Figure 2.25 shows temporal trends in weighted mean benthic cover in St. Croix and St. John between 2001 and 2006. In St. Croix, the highest weighted mean cover of live coral (27.5 ± 1.8%) was observed during February of 2001. Subsequently, weighted mean estimates of live coral cover ranged from as high as 8.0 ± 1.7% in August 2001 to as low as 2.9 ± 0.8% during October 2006. Although this trend is consistent with the hypothesis of a general temporal decline in coral cover in the USVI, the high percent cover observed in 2001 may have been due to an over sampling of lagoonal and reef crest sites around Buck Island in 2001. Sampling effort in subsequent years was at the same level as in 2001, but was spread over a greater area because of the expansion of the BIRNM, which may have resulted in greater numbers of samples being drawn from hardbottom habitats with lower coral cover. Observed temporal trends in weighted mean cover of other benthic organisms were unremarkable, although cover of algae (macroalgae, turf and crustose coralline algae) showed some oscillation around a global mean value (Figure 2.25).

In St. John, weighted mean live coral cover was highest in 2001 (8.4 ±1.8%) and steadily decreased to its lowest value in July 2006 (4.5 ±0.9%). There was also a slight, concomitant increase in mean weighted cover of macroalgae and turf algae between 2003 and 2006, as well as a consistent increase in the weighted-mean cover of crustose coralline algae between 2001 and 2006. Although consistent with the prevailing hypothesis of a temporal decline in coral cover and simultaneous increase in algal cover in the USVI, the observed trends (i.e., differences in coral and algal cover among years) were not significant (p>0.05). Observed cover of gorgonians was highest at 9.2 ±1.1% in 2003 and lowest (3.5 ±1.0%) in

2006, but there was no consistent or significant trend over time. Fire coral and sponges had low cover during all years.

### DPNR and EPA Coral Bioassessment/ Biocriteria Monitoring Program

A collaborative project between USVI DPNR and the EPA was initiated in 2006 to evaluate a stony coral bioassessment protocol for application of biocriteria development in the USVI. The project tested a bio-assessment protocol designed to determine anthropogenic effects on reef-building corals and laid the groundwork for implementing coral reef biocriteria to complement current water quality monitoring efforts of DPNR. Biocriteria, which identify thresholds of biological condition necessary for sustainable reefs, can be applied as water quality standards under authority of the Clean Water Act (CWA). This project was designed to determine which bioassessment indicators were responsive to anthropogenic over natural conditions. Regulatory activity under the CWA must be implemented only in response to human disturbance. Stony coral biocriteria will support regulatory standards and provide clear benchmarks for decision making and public information. Additionally, they inform and support management objectives such as permitting and establishment of MPAs.

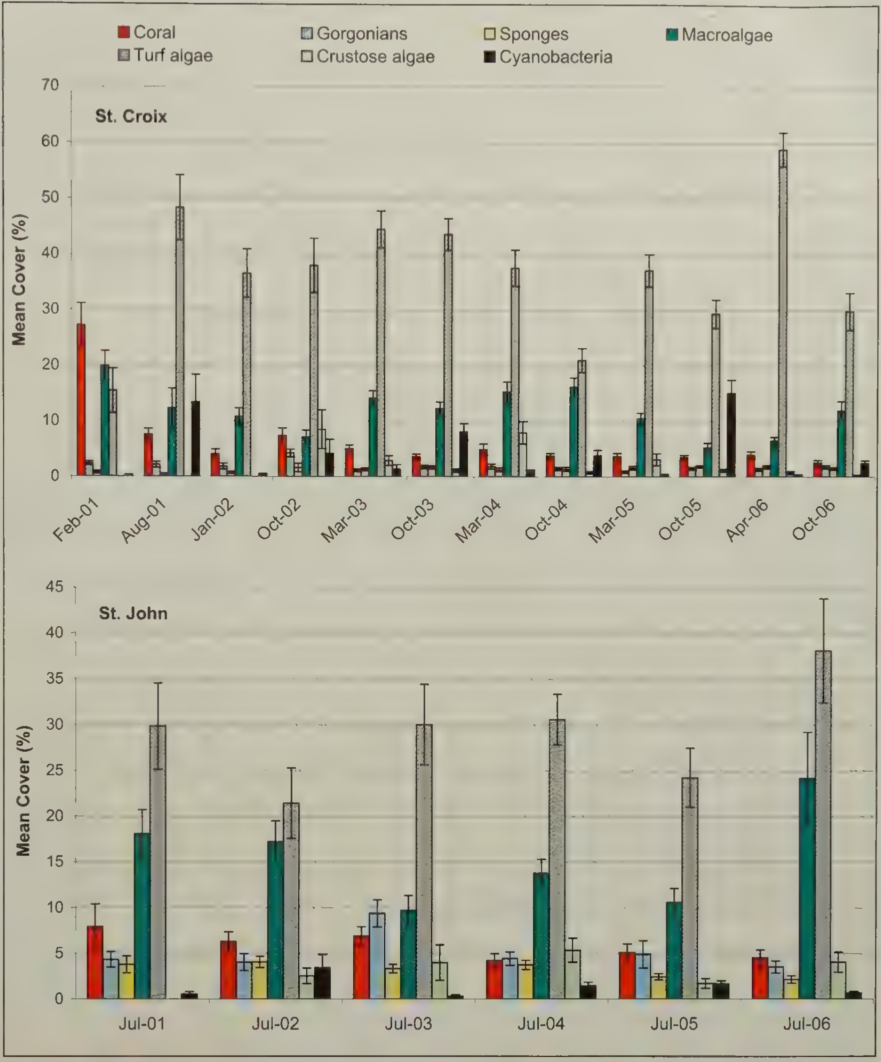


*Figure 2.25. Mean (±SE) percent cover of benthic organisms by survey period for St. Croix (top) and by year for St. John (bottom). Source: CCMA-BB.*

In 2006, EPA and DPNR led a field mission to test EPA's Stony Coral Rapid Bioassessment Protocol (RBP; Fisher, 2007). The RBP incorporates three underwater observations (colony identification, size and percent live tissue) into multiple indicators of stony coral condition. The indicators vary slightly from conventional condition measurements in order to evaluate value and sustainability, which are essential characteristics of regulatory assessments. Coral size was calculated from measurements of colony height, diameter and width. Three-dimensional colony surface area was estimated using conversion factors validated by three-dimensional photographic colony reconstruction (Courtney et al., 2007). Sixty-one sites within seven coastal management zones were surveyed around St. Croix along three suspected human disturbance gradients. Indicators were analyzed for change along the gradients using Pearson correlation analysis. Centers of human disturbance included Frederiksted pier, Christiansted Harbor and the south coast industrial channel. Candidate metrics evaluated for use as biocriteria included abundance and composition, physical stature, biological condition and community structure.

*Results and Discussion*

Transect area and indicator sensitivity were sufficient to delineate significant differences among stations. The protocol was found acceptable for use in a long-term monitoring program at USVI (Fore et al., 2006a). Evidence of a strong disturbance gradient was captured by several indicators at the industrial channel on the south coast of St. Croix (Figure 2.26). The chosen indicators are worthy of further consideration for CWA regulatory monitoring programs. The next steps in this project are application of the RBP at St. Croix using a probability-based sampling design and transfer of the program to DPNR for continued implementation.

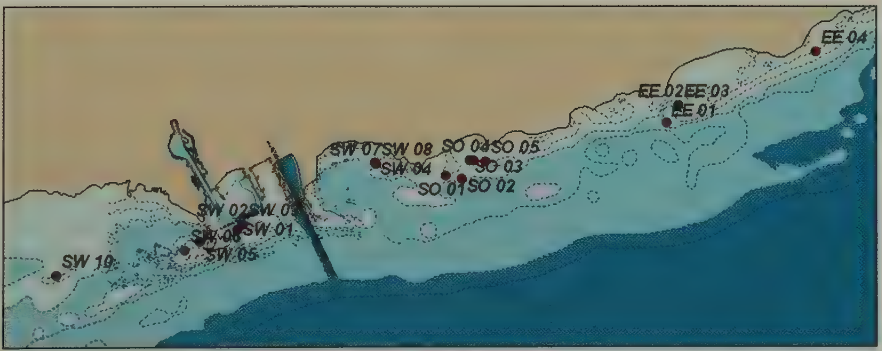


*Figure 2.26. The surface area of coral colonies distributed to the east and west of industrial docks in St. Croix was among those indicators showing a consistent response to human disturbance. Total surface area represents the sum of 3-D colony surface area for each colony in the transect. Positive distance from the main industrial dock represents east and negative distance west. Source: EPA.*

## NOAA Benthic Mapping and Characterization

NOAA's benthic habitat maps of the USVI encompass 490 km$^2$ of nearshore habitat (Kendall et al., 2001; Figure 2.27). More recently, CCMA-BB has collaborated with other NOAA program offices (NMFS, Office of Coast Survey, Office of Marine and Aviation Operations, Center for Operational Oceanographic Products and Services), the CFMC, NPS, DPNR-Division of Coastal Zone Management (DPNR-CZM) and DPNR-DFW, to characterize and map mid and deep water habitats in the USVI. From 2004 to 2006, scientists conducted annual missions to the USVI on board the NOAA ship R/V *Nancy Foster* to explore and characterize priority habitats from 10 to 1,000 m using high-resolution bathymetry, backscatter and complementary video data. The primary objective of the seafloor mapping project was to integrate abiotic data collected from acoustic sonar systems with biotic information obtained from underwater imagery systems (Remotely and Autonomously Operated Vehicles and drop/drift camera systems) and SCUBA dives to create accurate benthic habitat maps of deeper reef habitats. This project has been designed to meet the identified need for detailed bathymetric models of the USVI seafloor, as well as for continued benthic habitat characterizations and ecological inventories beyond the depth limits of optical remote sensing technologies (about 30 m). Integration of acoustical mapping technologies with traditional optical sensing methods enables the creation of a near-seamless map from the shoreline to 1,000 m water depth.

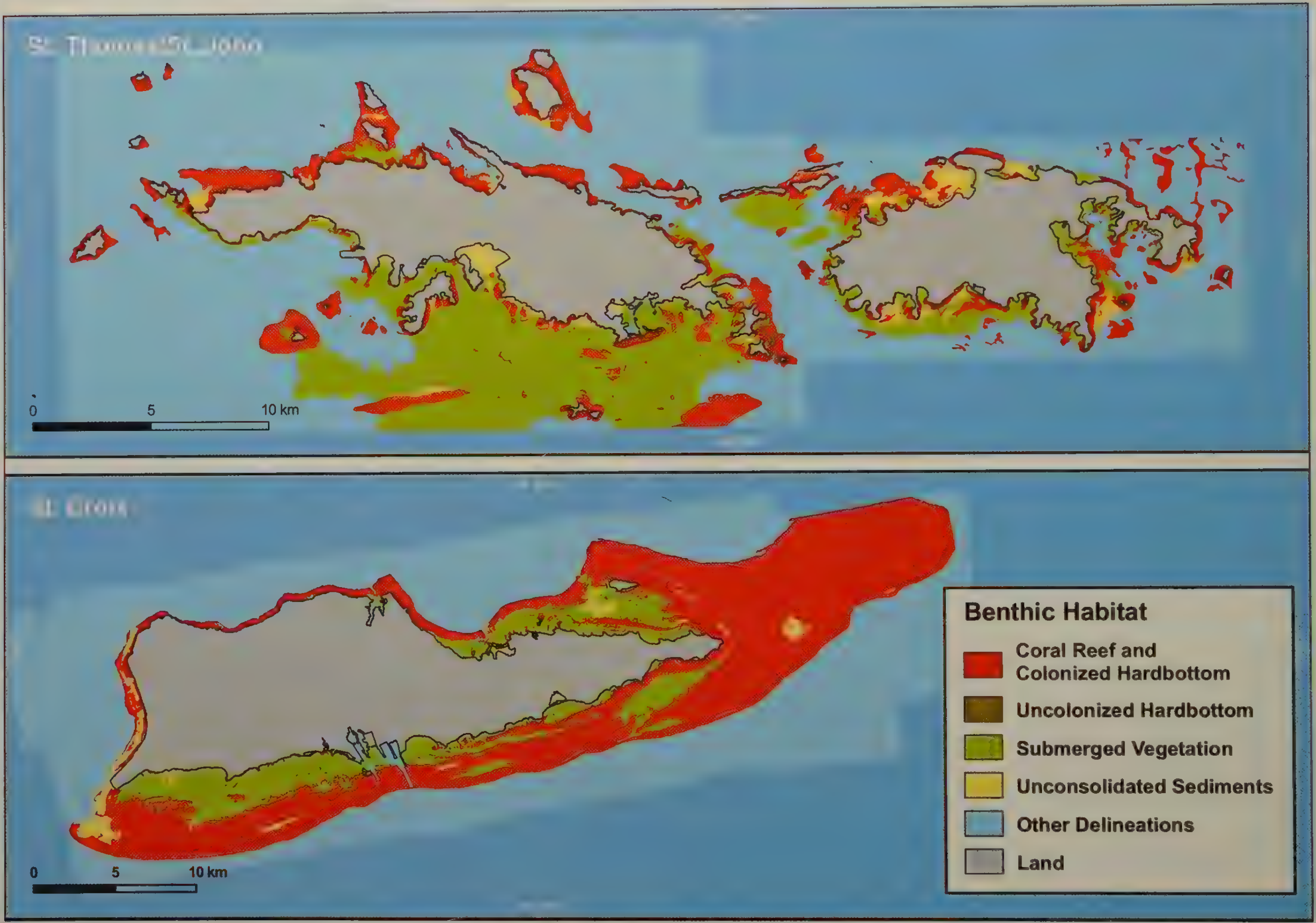


*Figure 2.27. Nearshore benthic habitat maps were developed by CCMA-BB based on visual interpretation of aerial photography and hyperspectral imagery. For more information, see: http://biogeo.nos.noaa.gov.*

### Methods

Areas surveyed to date in the USVI include BIRNM and the Salt River Bay National Historical Park and Ecological Preserve in St. Croix, the VICRNM in St. John, and the Grammanik Bank shelf break south of St. Thomas. Kongsberg EM1002, Reson 8124 and Reson 8101 multibeam echo-sounders were used to collect the bathymetry and backscatter imagery. A remotely operated vehicle (ROV) and drop camera captured underwater video and still images of the seafloor. To date, 292 km$^2$ of multibeam data (area ensonified), 2,659 ship track lines, and 110 km of ROV transects have been collected in the USVI (Table 2.3). These data sets have supported natural resource management in the USVI, and have helped NOAA continue to meet its commitment to map coral reef ecosystems.

*Table 2.3. Survey effort for NOAA CCMA-BB mid and deepwater seafloor mapping around the USVI. Source: C. Jeffrey, NOAA CCMA-BB.*

| METRICS | 2004 | 2005 | 2006 | TOTAL |
|---|---|---|---|---|
| Area Ensonified (km$^2$) | 101 | 110 | 81 | 292 |
| Ship Track Lines (km) | 1,282 | 1,138 | 239 | 2,659 |
| ROV Track Lines (km) | 30 | 70 | 10 | 110 |

*Results and Discussion*
Several web-accessible products have been generated from the seafloor characterization of the USVI (http://ccma.nos.noaa.gov/products/biogeography/usvi_nps/overview.html). A Benthic Habitat Viewer database comprising over 9,000 underwater seafloor images, along with information on each image's location, biological inventory, benthic habitat characterization, geomorphological structure, and seafloor terrain characteristics (i.e., bathymetry, slope, and rugosity) is available online at http://www8.nos.noaa.gov/bhv/bhvMapBrowser.aspx. Multibeam bathymetric data are available in a variety of formats including ASCII XYZ text files, ESRI Grids, and georeferenced TIFF images. Mosaics of multi-beam backscatter (geometrically and radiometrically corrected) are also available online as geotiffs and are ready for use in a Geographic Information System (GIS).

### NOAA Coral Bleaching Assessment

Data on the extent and severity of coral bleaching were collected during October 2005 by NOAA's CCMA-BB and the NPS SFCN as part of a bi-annual program to monitor coral reef ecosystems around BIRNM and EEMP. The regional coral bleaching event in 2005 was linked to anomalously warm SSTs centered on the northern Antilles near the USVI and Puerto Rico (NOAA Coral Reef Watch; http://coralreefwatch.noaa.gov/caribbean2005/). Data were analyzed to describe the extent, severity, and spatial patterns of coral bleaching before, during and after the event; correlate bleaching with environmental factors (i.e., *in situ* temperature and depth); describe taxonomic differences in bleaching severity; and discuss potential effects of coral bleaching and changes in the cover of live coral and algae on coral reefs and hardbottom areas between 2003 and 2006.

*Methods*
Underwater visual surveys were conducted biannually within a 48.7 km$^2$ area of the BIRNM and the EEMP. The area is comprised of a complex mosaic of habitat types, including coral reefs and other hard substrate, seagrasses, and soft sediments with varying depth and rugosity. Data on live unbleached and bleached coral were collected only on hard substrates within the study domain. Data on benthic composition were recorded along randomly selected 25 × 4 m belt transects (100 m$^2$). Survey sites were selected using a stratified random sampling design incorporating two strata (hard and soft benthic habitat types) derived from NOAA's nearshore benthic habitat maps (Kendall et al., 2001). Detailed information on field methodology is available online at http://ccma.nos.noaa.gov/ecosystems/coralreef/reef_fish.html.

Data on live coral cover, bleached coral, turf algae, water depth (m) and other benthic biota were collected during 617 benthic surveys completed between March 2003 and October 2006. Coral species were identified to the lowest possible taxon. During each survey, the percent areal cover occupied by bleached and unbleached coral colonies was estimated to the nearest 1 cm$^2$ or 0.1% in a two-dimensional plane perpendicular to the observer's line of vision within a 1 m$^2$ quadrat divided into 100 smaller (10 x 10 cm) squares. The quadrat was placed at five random locations alongside the transect, resulting in a sample within every 5 m interval along each transect. Colonies were considered entirely bleached if they contained white, blotchy/mottled or pale tissue. Diseased/dead coral was coral skeleton without living tissue but with corallites that were still visible and not colonized by other encrusting organisms. Normal coral colonies were those that were not bleached, diseased, or dead. Coral skeleton and other hard substrates with a mix of short, mat-like macroalgae less than 1 cm in height was categorized as turf algae (Steneck, 1988). Means and standard errors of percent cover of live (bleached and unbleached combined) coral, bleached coral and turf algae were calculated for each site. Sites were used as independent sample units and were considered replicates within survey missions and years. Multiple quadrat measurements (percent cover and depth) within each transect were averaged and average site values were then used to calculate means and standard errors of measured variables by survey mission and by year. Linear regression was used to examine the proportion of bleached coral cover and transect depth, and comparisons of bleached coral and algae cover between monitoring periods were conducted via non-parametric analysis of variance (ANOVA) statistical tests (Sokal and Rohlf, 1995). Spatial patterns of bleached corals within and among sampling missions were mapped using a GIS. Spatial autocorrelation and bleaching "hotspots" were determined with ESRI ArcGIS. Time series plots of the proportion of live coral that was normal or bleached were done from April 2005 through October 2006 to examine temporal trends in coral bleaching. Time series plots of mean percent cover of live coral and turf algae were done from April 2003 through October 2006 to identify temporal patterns and any effects of the 2005 bleaching event on the overall amounts of live coral and turf algae in the study area. Finally, taxonomic differences in living corals' susceptibility to bleaching were also examined.

*Results and Discussion*
Data from 94 randomly selected 100 m$^2$ transects over hardbottom habitats revealed that approximately 51% of live coral cover was bleached. Twenty-five of 30 coral species exhibited signs of bleaching, and species-specific bleaching patterns were variable throughout the study area. Although a weak but significant negative relationship ($r^2$=0.10, p=0.0220) with depth was observed, bleaching was evident at all depths (1.5-28 m). Bleaching was spatially autocorrelated (p=0.001) indicating that corals located in the seaward portion of the study area were most affected. Improved coral condition was observed upon subsequent monitoring missions during December 2005, March and October 2006 (Figure 2.28). Bleached coral incidence declined significantly and comprised 28%, 15% and 3% respectively, of total coral cover observed among transects. No spatial or depth correlations were observed in post-bleaching monitoring. Mortality estimates as a response to the bleaching event were not quantified; however, total coral cover for *Agaricia* spp. and *Porites porites* were significantly lower in October 2006 one year after the bleaching event. Mean live coral cover decreased by 23% in the BIRNM between 2003 and 2006 (Figure 2.29). Turf algae cover has been variable but has increased since the bleaching event.

Documentation of prior bleaching events has been limited to specific reefs with little information regarding broader spatial patterns within a coral reef ecosystem. These data documented the intensity, extent, and spatial variability of coral beaching across a large study area (47 km$^2$), and show the need to understand the effects of coral bleaching on demographic processes in a complex coral ecosystem. Furthermore, these data provide evidence that bleaching can have differential effects on components of coral reef ecosystems and that coral community structure is changing. The ecological implications of these changes are uncertain and should be the focus of future research. Understanding reef degradation and climate-induced stressors at various spatial and temporal scales, as well as recovery processes should be a priority for scientifically-based conservation and management.

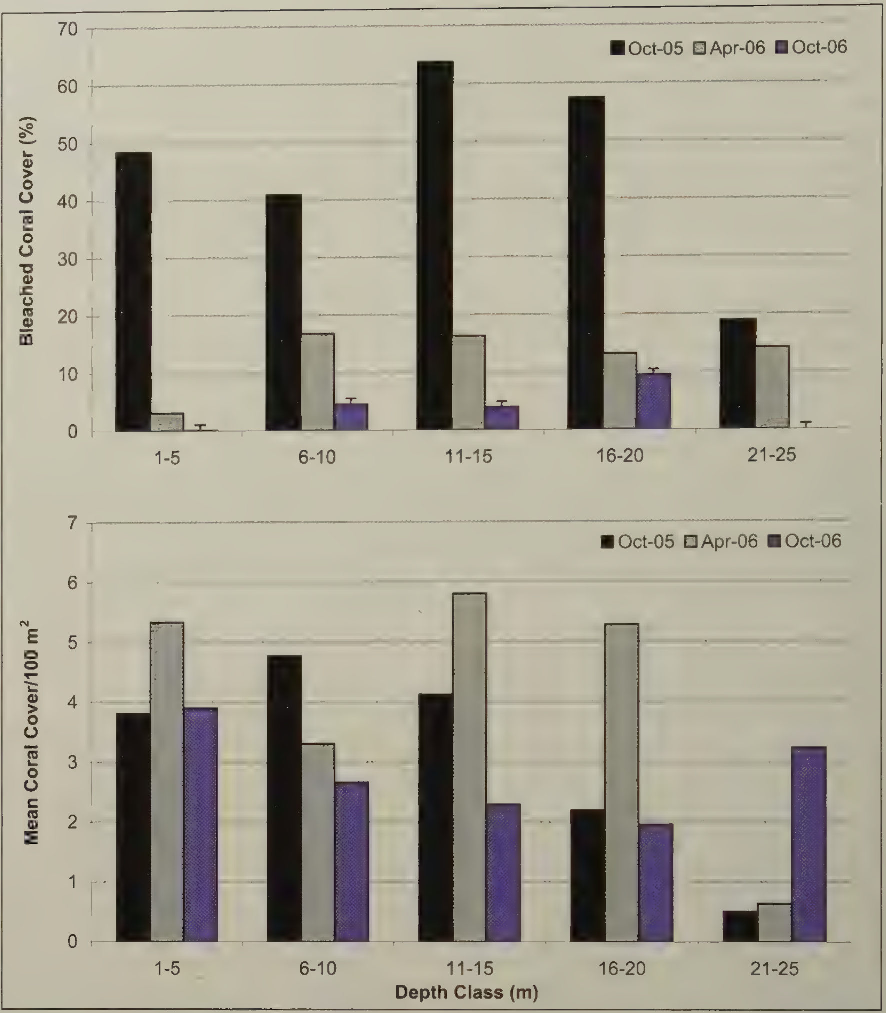


*Figure 2.28. Percentage of bleached coral (top) and mean live coral cover (bottom) at monitoring sites in St. Croix in October 2005, April 2006, and October 2006. Source: Clark et. al., in review.*

## *NOAA Fisheries (NMFS) USVI* Acropora *Mapping Project*

In May 2006, staghorn coral (*A. cervicornis*) and elkhorn coral (*A. palmata*) were formally listed as threatened under the Endangered Species Act (ESA), which marks the first time a coral species has been listed under the ESA since its inception in 1973. According to the act, a species is considered endangered if it is in danger of extinction throughout all or a significant portion of its range. A species is considered threatened if it is likely to become an endangered species within the foreseeable future.

NMFS has begun gathering data on the extant spatial distribution of acroporid corals throughout the Caribbean and Atlantic to aid in management and regulatory activities related to ESA listing. The goal is to designate critical habitat areas based on best available information about species distribution and habitat parameters throughout U.S. territories. Existing data sets on *Acropora* distribution are being compiled to develop a geodatabase for use in delineating critical *Acropora* habitat. Example maps can be found in the National Level Activities chapter.

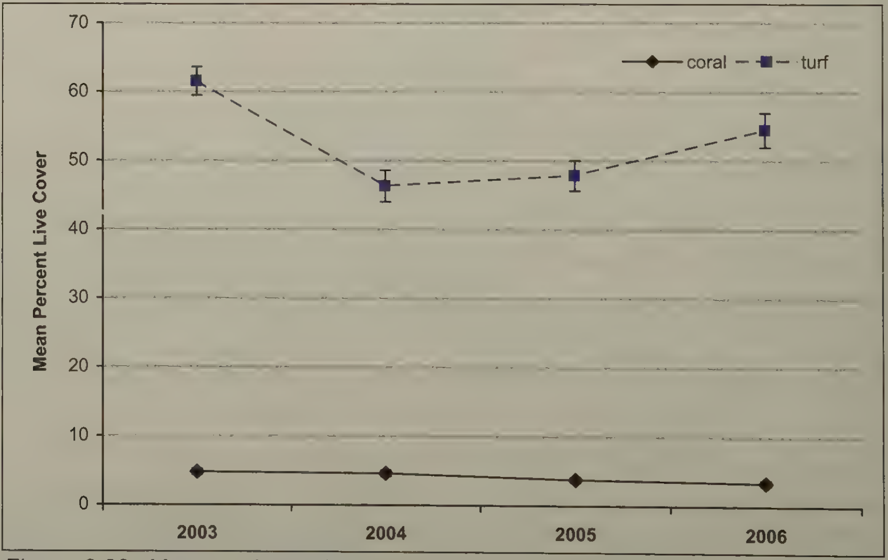


*Figure 2.29. Mean and standard error for live coral and turf algae cover within BIRNM study area, 2003-2006. Source: Clark et al., in review.*

### *Results and Discussion*

GIS databases have been compiled for the islands of St. Croix and St. John, based on data submitted by the NPS, the USGS and NOAA's CCMA-BB. To date, this project has not obtained data on acroporid species distribution for St. Thomas. In St. Croix, NPS staff has identified 2,492 *A. palmata* colonies greater than 1 m in size at 455 of 617 sites within BIRNM (Mayor et. al., 2006). CCMA-BB documented the presence of *A. palmata* at 32 of 815 hardbottom sites within the BIRNM and at 11 of 430 sites within the northern EEMP. In St. John, USGS staff surveyed 1,643 sites within 11 bays in the VINP and found 3,314 *A. palmata* colonies at 1,494 of the sites visited. Of the 65 sites without colonies, 51 contained *A. palmata* fragments with living tissue. USGS also conducted surveys at 149 sites in two bays outside of the VINP (Dittliff Point and Newfound Bay) and found 313 colonies of *A. palmata*.

*A. cervicornis* has not received as much research attention as *A. palmata*, and much less data has been provided about the distribution and incidence of this species in the USVI. CCMA-BB staff documented the presence of *A. cervicornis* at 12 of 815 hard bottom sites within the BIRNM and at two of 430 sites within the EEMP, but they did not observe any colonies at 39 additional other sites visited in northeast St. Croix. In St. John, NOAA staff conducted surveys at 490 sites. *A. cervicornis* was observed at four of 258 sites in the VINP but was not seen at 39 sites within the VICRNM. *A. cervicornis* was also documented at one of 195 sites surveyed outside of the VINP and the VICRNM.

*Summary of Overall Condition, Status and Trajectory of USVI Benthic Communities*

Prior to the 2005-2006 bleaching and disease events, reef resilience was observed at three of six study sites monitored by NPS SFCN (two in VINP, one in BIRNM); the data showed that statistically significant increases in coral cover had occurred in the recent past (Miller et al., 2005). Long-term coral reef monitoring throughout the territory revealed the devastating consequences of elevated SST and its effects on coral reefs. Losses of over half the live coral cover on reefs multiple-centuries old show their vulnerability to the unprecedented intensity of natural and anthropogenic stressors found in the territory. The full effect of these losses may not be known for years but have the potential to influence fisheries, shoreline protection and tourism within the territory.

## ASSOCIATED BIOLOGICAL COMMUNITIES

The previous USVI report (Jeffrey et al., 2005) focused on data sets from four monitoring and assessment programs to characterize community structure, biomass, trophic structure, and the size frequency distribution of fish assemblages in the USVI. Two of these four programs continue reef fish monitoring, and one new fish tracking study and a lobster population assessment were initiated during this reporting cycle (Table 2.1). Data from a UVI-CMES SPAG monitoring program (sites initiated both prior to and during this reporting period) have been included as well. Data from DPNR-DFW's fishery-dependent Commercial Catch Reporting and TIP (port sampling) Programs were not available for inclusion in this report, and as a result are not discussed in detail in this section, but a brief description of these programs and observed trends are discussed in the Fishing threat section of this chapter. SEAMAP-C data from DPNR-DFW's fishery-independent monitoring program are available for reef fish as well as for conch in St. Croix back reef embayments. Data collection methods did not change significantly between reporting periods for ongoing monitoring programs (Nemeth et. al., 2004; NOAA, http://ccma.nos.noaa.gov/ecosystems/coralreef/reef_fish/protocols.html ).

### *NOAA CCMA-BB Monitoring of Temporal Trends in Fish Communities of the USVI*

The background, goals, objectives and methods for CCMA-BB's Caribbean Coral Reef Ecosystem Monitoring (CREM) project are provided in the Benthic Habitats section. All of the data collected by CCMA-BB and local partners are available at http://www8.nos.noaa.gov/biogeo_public/query_main.aspx.

*Results and Discussion*

Between 2001 and 2006, a total of 1,275 and 849 locations were sampled in St. Croix and St. John respectively. Data from surveys in St. Croix suggest that reef fish assemblages were variable and showed seasonal patterns in time. In St. Croix, the mean density and biomass of reef fishes typically were lower in spring surveys (February–March) than in late summer or fall surveys (August–November) for all years (Figure 2.30). During spring months, there was a general increase in fish density between 2001 and 2006, but that increase may not be significant. Mean (±SE) biomass also appeared to increase during spring months from 2,663 ± 293 g/100 m$^2$ in 2001 to its highest at 7,325 ± 1,689 g/100 m$^2$ in 2004. Mean density and biomass of fishes were more variable during fall months. Mean (±SE) fall densities were highest during October of 2002 (314 ± 52 fishes/100 m$^2$) and almost three times that of August 2001 (74 ± 7 fishes /100 m$^2$). In fall of 2004, mean (±SE) fish density decreased below 2001 levels, but showed a subsequent but steady increase throughout 2006. Mean fall biomass was also highest during 2002 and variable in subsequent years (Figure 2.30).

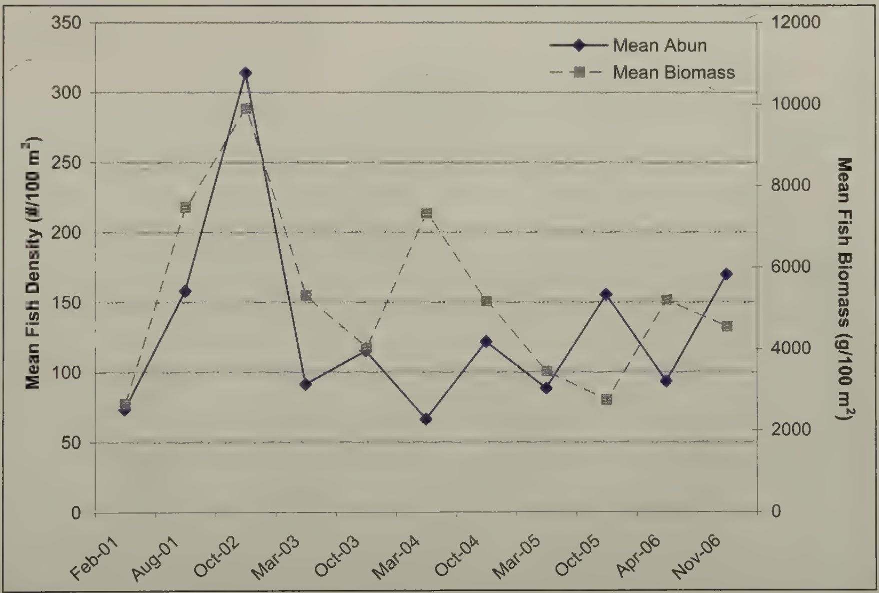


*Figure 2.30. Mean (± SE) fish assemblage abundance and biomass in St. Croix, USVI. Source: NOAA CCMA-BB.*

In St. John, surveys were conducted during summer months, therefore observations of seasonal patterns were not possible. Reef fish densities showed very little variation among years and ranged from a low of 150 ± 18 fish per 100 m$^2$ in 2004 to 172 ± 21 fish per 100 m$^2$ in 2006 (Figure 2.31). Mean biomass was more variable among years and was highest at

6,148 g/100 m$^2$ in 2004 and lowest in 2006 (3,034 ± 379 g/100 m$^2$).

Reef fish assemblages were also temporally variable in trophic (Table 2.4) and taxonomic structure. In St. Croix, herbivores comprised more of the biomass than piscivores for all survey periods except during August 2001 (Figure 2.32). In St. John, herbivores also consistently comprised more of the biomass than piscivores for all years except 2003 (Figure 2.32). Fluctuations in relative biomass of herbivores and piscivores most likely relate to the occurrence of large schooling jacks or snappers during surveys.

The density of commercially important groupers (Table 2.5; species from the genera *Cephalopholis*, *Epinephelus*, and *Mycteroperca)* remain at low levels and were variable among years with no consistent trend. Most were observed either on or near reef and hardbottom areas. In St. Croix, the highest densities of grouper were observed in March 2003 (3 ± 1 grouper per 100 m$^2$) and the lowest were seen in 2001 (approximately one fish per 100 m$^2$). *C. fulvus* was the most common grouper species seen for all years and were often larger than the known size of sexual maturity. Fewer *E. gutattus* were observed, and only one juvenile Nassau grouper (*E. striatus)* was encountered during April 2006. Less than 3% of snappers and groupers observed on transects between 2001 and 2007 were ≥35 cm (CCMA-BB, unpub. data).

In St. John the density of commercially important groupers was lower than that observed in St. Croix and was about one fish per 100 m$^2$ for all years. *C. fulvus* was the most common grouper species observed and only one *E. striatus* juvenile was observed between 2003 and 2006.

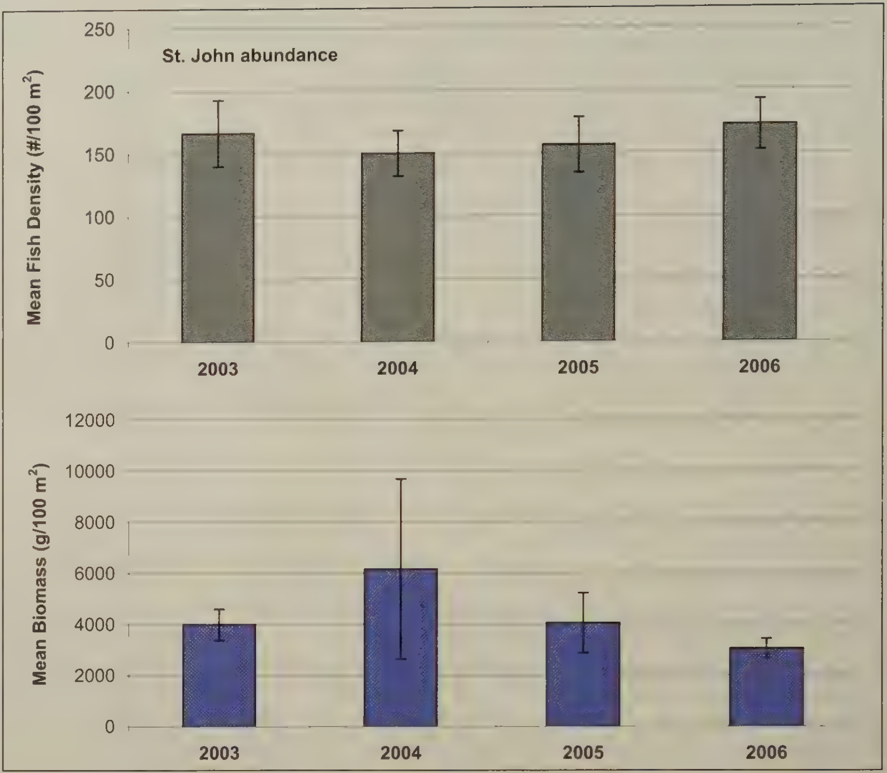


*Figure 2.31. Mean (± SE) fish assemblage abundance and biomass in St. John, USVI. Source: NOAA CCMA-BB.*

*Table 2.4. Trophic guilds used to determine trophic biomass ration of fishes in the USVI. Source: Randall, 1967.*

| TROPHIC GUILD | FOOD TYPE | EXAMPLE TAXA |
|---|---|---|
| Herbivores | Marine plants | Damselfish, parrotfish, surgeonfish |
| Piscivores, mobile invertivores/piscivores | Other fish, crabs | Red hind, other groupers, snappers |
| Mobile invertivores, sessile invertivores, zooplanktivores, generalized carnivores | Crustaceans, corals, zooplankton, etc. | Spanish hogfish, wrasses, gobies, filefish, butterflyfish, blennies, cardinal fishes, angelfish, squirrel fishes, goatfish scadblennies |

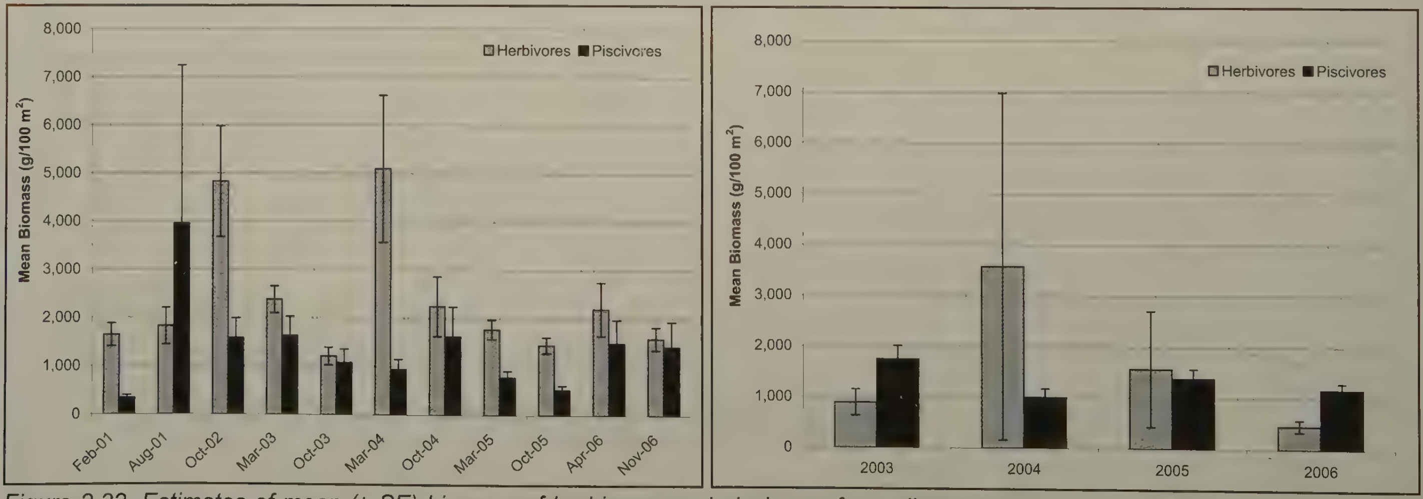


*Figure 2.32. Estimates of mean (± SE) biomass of herbivores and piscivores from all surveys in St. Croix (left) and St. John (right). Source: NOAA CCMA-BB.*

### UVI-CMES Monitoring of St. Thomas Coral Reef Fishes

Fish surveys were conducted off St. Thomas by UVI-CMES as part of the TCRMP between 2003 and 2006. The surveys were conducted in parallel with fish monitoring on St. Croix between 2003 and 2005, and results were published annually in reports to DPNR-CZM (Nemeth et al., 2004b; Nemeth et al., 2005; Nemeth et al., 2006b). In 2003 fish surveys were conducted on six sites south of St. Thomas (Figure 2.13) within three strata (nearshore, mid-shelf and shelf-edge). In 2004, nearshore sites were dropped from the survey and in 2005 and 2006 one additional mid-shelf site and one shelf-edge site were added (Figure 2.13). Detailed survey methodology can be found in Nemeth et al., 2004b.

*Results and discussion*

Comparison of pooled data between years indicated no pronounced changes in fish assemblage structure on reef sites from 2003 to 2006 in St. Thomas. Total fish abundance was not significantly different over time (p=0.080) nor was average species richness (p=0.538). A comparison of repeated sites shows fairly high variability in fish abundance between and within sites (Figure 2.33a), but lower variability in species richness and diversity (Figures 2.33b and 2.33c).

Fish abundance by family was also variable over time, apparently due to natural variation, seasonality and variable recruitment (Nemeth et al., 2006b). In particular, acanthurid and scarid numerical abundance varied over time on midshelf reefs, and lutjanid and serranid abundance varied on shelf-edge sites that hosted SPAGs. The most common fishes on all sites were the blue chromis (*Chromis cyanea*) and bicolor damselfish (*Stegastes partitus*). Herbaceous pomacentrids (*Stegastes planifrons* and *S. diencaeus*) were numerically abundant at nearshore and mid-shelf sites but were nearly absent on the shelf-edge. Scarids, represented primarily by the princess, striped and redband parrotfish (*Scarus iserti*, *S. taeniopterus* and *Sparisoma aurofrenatum*) were also much more abundant nearshore than offshore, with most individuals under 20 cm. The creole wrasse (*Clepicus parrae*), a planktivore, was very common on offshore sites but was rare at all but one mid-shelf site (Nemeth et al., 2006b).

Commercially important groupers and snappers ranged from common to rare on St. Thomas reef sites from 2003 to 2006. The large bodied serranids, represented by the red hind (*E. guttatus*), Nassau grouper (*E. striatus*), yellowfin grouper (*Mycteroperca*

*Table 2.5. Species of commercially important snappers (Lutjanidae) and groupers (Serranidae) for which estimates of mean biomass density (g/m$^2$) were calculated for VINP, St. John and the BIRNM, St. Croix. Source: Appeldoorn et al., 1992.*

| FAMILY | SPECIES | COMMON NAME |
|---|---|---|
| *Lutjanidae* (snapper) | *Lutjanus analis* | mutton snapper |
| | *Lutjanus apodus* | schoolmaster |
| | *Lutjanus griseus* | gray snapper |
| | *Lutjanus jocu* | dog snapper |
| | *Lutjanus mahogoni* | mahogany snapper |
| | *Lutjanus synagris* | lane snapper |
| | *Ocyurus chrysurus* | yellowtail snapper |
| *Serranidae* (grouper) | *Cephalopholis cruentatus* | graysby |
| | *Cephalopholis fulvus* | coney |
| | *Epinephelus guttatus* | red hind |
| | *Epinephelus morio* | red grouper |
| | *Mycteroperca tigris* | tiger grouper |

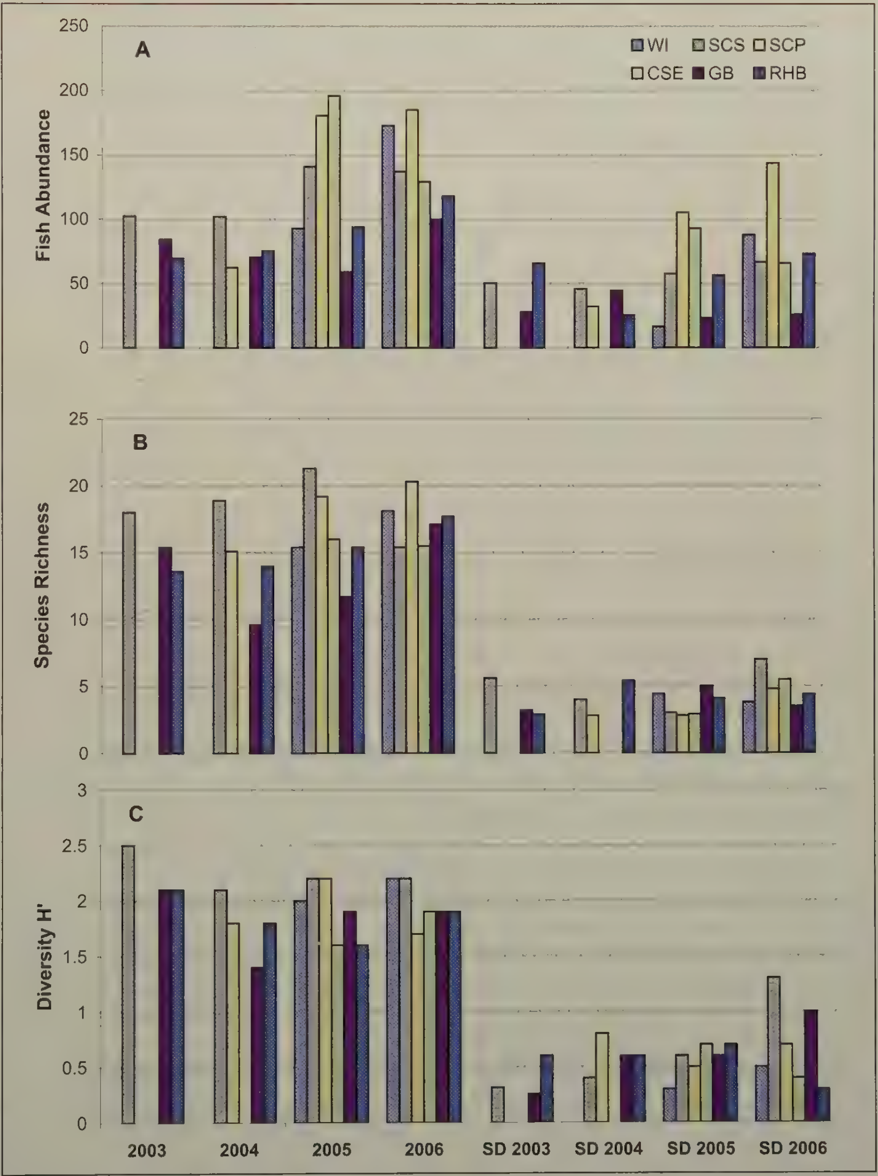


*Figure 2.33. Reef fish assemblage structure across six St. Thomas sites from 2003-2006. a) Average abundance, b) Average species richness, and c) Average Shannon diversity (H'). Sites are as follows: WI=Water Island, SCS=Seahorse Cottage Shoal, SCP=South Capella, CSE=College Shoal East, GB=Grammanik Bank, RHB=Red Hind Bank. Source: E. Kadison, UVI-CMES.*

venenosa), yellowmouth grouper (*M. interstitialis*) and tiger grouper (*M. tigris*) were all observed at offshore sites, but red hind and Nassau were absent at mid-shelf and inshore sites. Lutjanids were observed at all sites but were also much more abundant on offshore sites and were represented primarily by schoolmaster (*Lutjanus apodus*), cubera (*L. cyanopterus*) and yellowtail snapper (*Ocyurus chrysurus*). Results for 13 selected serranid and lutjanid species of commercial importance are shown in Table 2.6. Changes in the abundance of these fishes over the sampling years appeared to be primarily due to seasonality. The occurrence of large groupers and snappers on the shelf off St. Thomas, however, is in contrast to fish surveys made off St. Croix, where these species are rarely documented (Toller, 2002; Jeffrey et al., 2005). Their presence in St. Thomas is likely due to the two fishery reserves that protect grouper and snapper SPAGs and over 45 km$^2$ of the south shelf edge from fishing.

*Table 2.6. Mean density and biomass of commercially important snappers (Lutjanidae) and groupers (Serranidae). Results from St. Thomas visual surveys 2003-2006. Source: E. Kadison, UVI-CMES.*

| | | 2003 | | | | 2004 | | | | 2005 | | | | 2006 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Scientific Name** | **Common Name** | Total No. | Density$^1$ | Biomass Total (g) | Biomass Density$^2$ (g/m$^2$) | Total No. | Density$^1$ | Biomass Total (g) | Biomass Density$^2$ (g/m$^2$) | Total No | Density$^1$ | Biomass Total (g) | Biomass Density$^2$ (g/m$^2$) | Total No | Density$^1$ | Biomass Total (g) | Biomass Density$^2$ (g/m$^2$) |
| **Lutjanidae** | | | | | | | | | | | | | | | | | |
| *Lutjanus analis* | mutton snapper | 3 | 0.038 | 2,015.0 | 4.198 | - | - | - | - | 2 | 0.033 | 486.4 | 1.351 | 4 | 0.067 | 4,447.6 | 12.354 |
| *Lutjanus apodus* | school-master | 10 | 0.125 | 7,824.9 | 16.302 | 72 | 2.000 | 19,648.5 | 81.869 | 209 | 3.483 | 53,138.7 | 147.608 | 128 | 2.133 | 79,049.3 | 219.581 |
| *Lutjanus griseus* | gray snapper | 3 | 0.038 | 233.1 | 0.486 | 4 | 0.111 | 2,058.5 | 8.577 | 29 | 0.483 | 5,545.7 | 15.405 | 15 | 0.250 | 3,855.1 | 10.709 |
| *Lutjanus jocu* | dog snapper | 3 | 0.038 | 1,840.8 | 3.835 | - | - | - | - | 3 | 0.050 | 2,336.3 | 6.490 | 4 | 0.067 | 10,468.2 | 29.078 |
| *Lutjanus mahogani* | mahogany snapper | 1 | 0.013 | 286.0 | 0.596 | 2 | 0.056 | 147.8 | 0.616 | 13 | 0.217 | 3,081.7 | 8.560 | 2 | 0.033 | 777.1 | 2.159 |
| *Lutjanus cyanopterus* | cubera snapper | 4 | 0.050 | 7,177.0 | 14.952 | 3 | 0.083 | 5,382.7 | 22.428 | 45 | 0.750 | 80,740.8 | 224.280 | 180 | 3.000 | 322,963.3 | 897.120 |
| *Ocyurus chrysurus* | yellowtail snapper | 86 | 1.075 | 13,925.3 | 29.011 | 6 | 0.167 | 873.3 | 3.639 | 11 | 0.183 | 1,489.8 | 4.138 | 22 | 0.367 | 11,240.9 | 31.225 |
| **Serranidae** | | | | | | | | | | | | | | | | | |
| *Epinephelus guttatus* | red hind | 17 | 0.213 | 12,384.0 | 25.800 | 2 | 0.056 | 919.2 | 3.830 | 15 | 0.250 | 3,811.7 | 10.588 | 23 | 0.383 | 11,974.1 | 33.261 |
| *Epinephelus striatus* | Nassau grouper | 3 | 0.038 | 4,137.6 | 8.620 | - | - | - | - | 2 | 0.033 | 1,192.1 | 3.311 | 1 | 0.017 | 1,379.2 | 3.831 |
| *Mycteroperca tigris* | tiger grouper | 6 | 0.075 | 5,545.7 | 11.554 | 1 | 0.028 | 1,242.2 | 5.176 | 22 | 0.367 | 11,624.6 | 32.291 | 3 | 0.050 | 3,726.6 | 10.352 |
| *Mycteroperca venenosa* | yellowfin grouper | 1 | 0.013 | 2,488.0 | 5.183 | 1 | 0.028 | 703.2 | 2.930 | 2 | 0.033 | 3,066.3 | 8.518 | - | - | - | - |
| *Mycteroperca interstitialis* | yellow-mouth grouper | - | - | - | - | - | - | - | - | 1 | 0.017 | 606.3 | 1.684 | 1 | 0.017 | 1,242.2 | 3.451 |

**Notes:** Total No.=Sum of all individuals observed in transects at sites surveyed. Density$^1$= mean numeric density (number of individuals observed per replicate sample). Data from all sites pooled. Total Biomass=Species -specific median weight per size class multiplied by the number of individuals observed in each size class, summed. Density$^2$= Mean biomass density (weight per m$^2$). Calculated as total weight of all individuals divided by total survey area (number of transects x 60 m$^2$ per transect).

Recent studies have shown that extensive coral bleaching leading to the reduction of live coral cover can cause dramatic changes in fish community structure and a reduction in fish diversity (Jones and Syms, 1998; Graham et al., 2006; Feary et al., 2007a). With the exception of a few species that are lost rapidly due to their specialized use of live coral for diet or shelter, most community shifts do not occur at detectable levels until several years after the event (Graham et al., 2007). Although not well understood, lag effects on fish community structure are believed to be a function of lost recruitment cues for larval reef fishes (Feary et al., 2007b) and loss of fish habitat as dead coral skeletons are worn away, reducing reef complexity (Graham, 2007). Continued fish monitoring over the next several years in the USVI will be important to determine if additional changes occur as a result of the coral bleaching event of 2005.

## USVI DPNR-DFW Monitoring of St. Croix Coral Reef Fishes

The abundance, size and species composition of fish populations were monitored annually at eight coral reef sites around St. Croix between 2002 and 2005 as part of the TCRMP. The DPNR-DFW coordinated reef fish monitoring on St. Croix in parallel with a compatible reef fish monitoring study by UVI-CMES on St. Thomas. Monitoring was funded through an award from NOAA to DPNR-CZM as part of the National Coral Reef Ecosystem Monitoring Program. Fish census methodology was reported in Jeffrey et al.(2005) and Nemeth et al.(2004b and 2005). The St. Croix component of the reef fish monitoring program was terminated in 2006 due to staff limitations and personnel turnover within DFW.

*Results and Discussion*

Three years of fish survey data from eight St. Croix reef sites were analyzed for metrics of reef fish assemblage structure. Comparisons of aggregated data (all sites pooled) among years indicate that there were no pronounced changes in reef fish assemblage structure during the monitoring period. Significant differences were not detected for average fish abundance over time (p=0.086)], or for average fish species richness over time (p=0.16). This finding reflects the high variability in fish abundance among sites within any given year. Variability in abundance was generally reduced when individual sites were compared among years (Figure 2.34a). Similar site-to-site patterns of variability were observed for fish richness and diversity (Figures 2.34b and 2.34c).

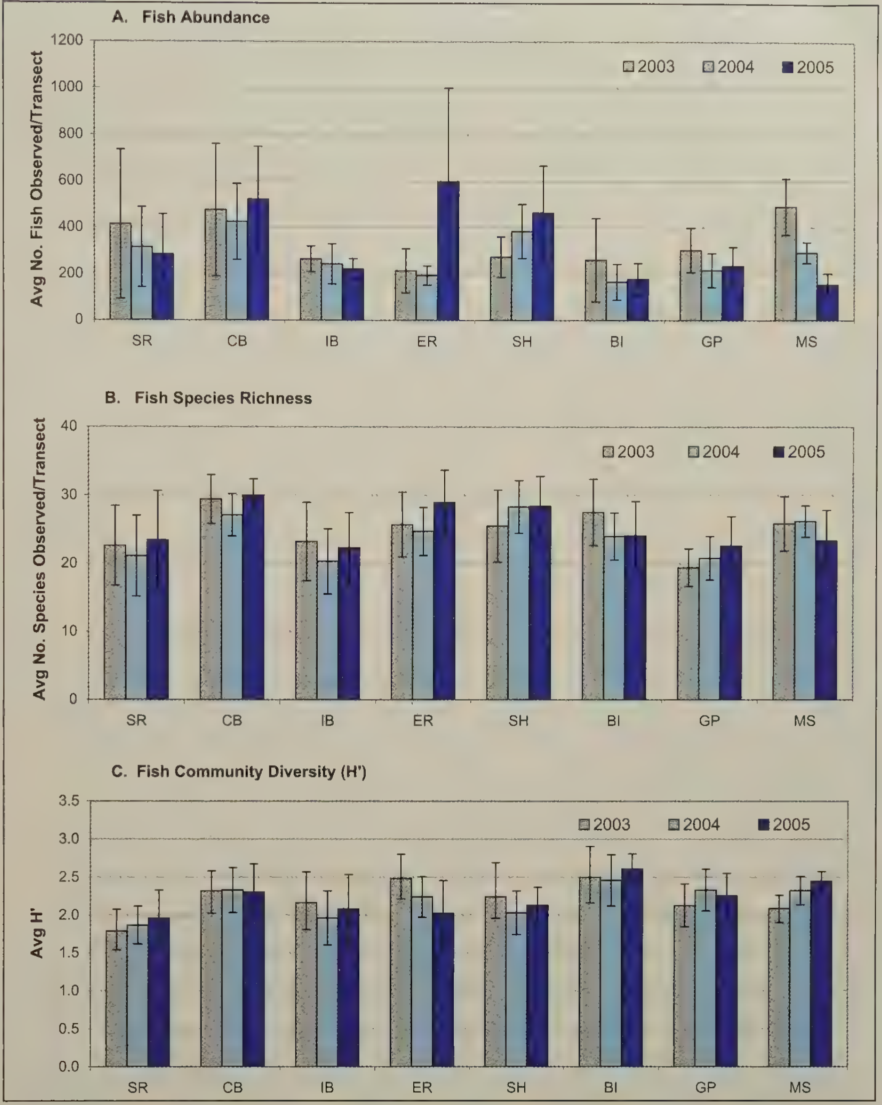


*Figure 2.34. Reef fish assemblage structure across eight St. Croix reef sites. Data are from belt transect surveys conducted in 2003, 2004 and 2005. A. Average abundance. B. Average species richness. C. Average Shannon diversity (H'). Reef sites are as follows: SR=Salt River, CB=Cane Bay, IB=Isaacs Bay, ER=Eagle Ray, SH=Sprat Hole, BI=Buck Island, GP=Great Pond, MS=Mutton Snapper spawning aggregation site. Source: W. Toller, ASI.*

The trophic composition of St. Croix reef fish assemblages was analyzed after pooling sites for each year. In all years, omnivores dominated the reef fish assemblage in terms of biomass. Omnivores also dominated assemblages in terms of numeric abundance (82-85% of all fish observed), primarily due to highly abundant planktivorous or omnivorous wrasses (Labridae) and damselfishes (Pomacentridae). Herbivore biomass represented approximately 30% of entire assemblage. Piscivores contributed least to assemblage biomass (10-14%) and were least abundant numerically (2.7-3.1% of all fish observed). Among the years observed, there was no clear indication of a change in trophic composition through time.

As documented previously (Jeffrey et al., 2005), commercially important snappers and groupers remained comparatively uncommon in St. Croix visual surveys during the recent survey period. Results for 12 selected lutjanid and serranid species of commercial importance are shown in Table 2.7. Mean numeric density and mean biomass density was dominated by small-bodied species. The highest densities were observed for coney (*C. fulvus*), graysby (*C. cruentata*), schoolmaster (*L. apodus*) and mahogany snapper (*L. mahogoni*). No large-bodied serranids of the genus *Mycteroperca* were observed in belt transects in any of the three years. Mutton snapper (*L. analis)* were rarely encountered (Table 2.7).

The quantity of herbivorous reef fishes harvested in the St. Croix commercial fishery has increased during the past decade (W. Tobias, pers. comm.), making scarids a commercially important species group. Three species dominate St. Croix landings of scarids: stoplight parrotfish (*Sparisoma viride*), redtail parrotfish (*S. chrysopterum*) and redfin parrotfish (*S. rubripinne*; Tobias, 2004; Toller and Tobias, 2005; Trumble et al., 2006). A size frequency distribution for scarids observed during 2003-2005 is shown in Figure 2.35. Comparison among years did not indicate a trend towards decreasing mean size during the study period. However, few parrotfish >30 cm, which are targets of the commercial fishery, were observed during the monitoring period. The observed low frequency with which parrotfish attain large body size may be indicative of increased fishing mortality rates.

Table 2.7. Mean density and biomass of commercially important snappers (Lutjanidae) and groupers (Serranidae). Results from St. Croix visual surveys (DPNR-DFW). Source: W. Toller.

| | | 2003 | | | | 2004 | | | | 2005 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Species | Common Name | Total No. | Density[1] | Biomass Total (g) | Density[2] ($g/m^2$) | Total # | Density[1] | Biomass Total (g) | Density[1] | Total # | Density[1] | Biomass Total (g) | Density[2] ($g/m^2$) |
| **Lutjanidae** | | | | | | | | | | | | | |
| *Lutjanus analis* | Mutton snapper | 1 | 0.013 | 1,540.5 | 0.333 | 0 | - | - | - | 1 | 0.014 | 1,540.5 | 0.352 |
| *Lutjanus apodus* | School-master | 27 | 0.351 | 7,407.7 | 1.603 | 24 | 0.316 | 4,899.4 | 1.074 | 13 | 0.178 | 6,225.8 | 1.421 |
| *Lutjanus griseus* | Gray snapper | 0 | - | - | - | 0 | - | - | - | 0 | - | - | - |
| *Lutjjanus jocu* | Dog snapper | 0 | - | - | - | 0 | - | - | - | 0 | - | - | - |
| *Lutjanus mahogoni* | Mahogany snapper | 40 | 0.519 | 3,661.6 | 0.793 | 25 | 0.329 | 1,695.7 | 0.372 | 21 | 0.288 | 1,760.8 | 0.402 |
| *Lutjanus synagris* | Lane snapper | 0 | - | - | - | 0 | - | - | - | 0 | - | - | - |
| *Ocyurus chrysurus* | Yellowtail snapper | 30 | 0.390 | 4,589.1 | 0.993 | 4 | 0.053 | 1,211.4 | 0.266 | 47 | 0.644 | 9,504.1 | 2.170 |
| **Serranidae** | | | | | | | | | | | | | |
| *Cephalopholis cruentata* | Graysby | 105 | 1.364 | 7,342.1 | 1.589 | 91 | 1.197 | 6,329.9 | 1.388 | 94 | 1.288 | 5,935.2 | 1.355 |
| *Cephalopholis fulvus* | Coney | 188 | 2.442 | 13,039.7 | 2.822 | 122 | 1.605 | 8,090.5 | 1.774 | 141 | 1.932 | 7,552.9 | 1.724 |
| *Epinephelus guttatus* | Red hind | 16 | 0.208 | 3,057.6 | 0.662 | 2 | 0.026 | 1,419.4 | 0.311 | 12 | 0.164 | 2,259.7 | 0.516 |
| *Epinephelus morio* | Red grouper | 0 | - | - | - | 0 | - | - | - | 0 | - | - | - |
| *Mycteroperca tigris* | Tiger grouper | 0 | - | - | - | 0 | - | - | - | 0 | - | - | - |

**Notes**: Total No. = Sum of all individual observed in all transects among the 8 sites surveyed; Total No. = Sum of all individual observed in all transects among the 8 sites surveyed; Total Biomass = Species-specific median weight per size class multiplied by the number of individuals observed in each size class, summed for all size classes; Density[2] = Mean biomass density (weight per $m^2$). Calculated as total weight (grams) of all individuals divided by total survey area (number of transects x 60 $m^2$ per transect).

### SEAMAP-C Reef Fish Assessments

A new analysis has been conducted of data collected during surveys of reef fishes using traditional fishing gear during 1992-2002 (Whiteman, 2005). Earlier analyses found that 60% of the original data were missing from the program database, thereby limiting the accuracy of any conclusions drawn from the data set (Pagan et al., 2004). Details of sampling methodology are provided in Gomez (2000); Tobias et al. (2002); and Whiteman (2005). Briefly, sample areas were defined northeast of St. Croix and south of St. John. Sampling consisted of deploying a series of fish traps as well as baited hand lines. Total or fork length, weight, sex and developmental stage of gonads were recorded for all fish.

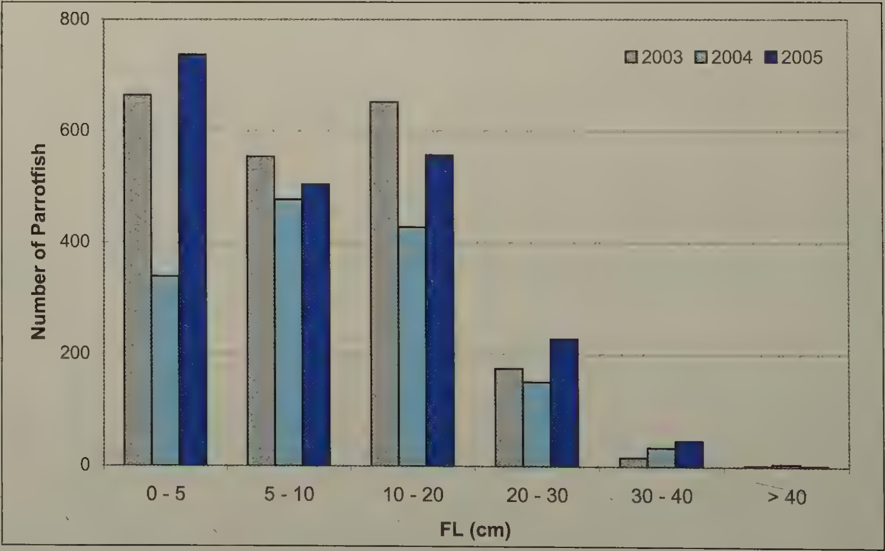


Figure 2.35. Size-frequency distribution of parrotfishes (all Scarids pooled) observed in St. Croix monitoring reef fish surveys, 2003-2005. Source: W. Toller, ASI.

It is important to note that while this data provides a baseline for local fishery resources, confounding variables such as differences in sampling locations between sampling years, catch variation due to gear type and differences in gear deployment between implementation of the study and actual fishing practice, reduce the ability of managers to attribute observed changes to actual shifts in fishery populations. Several recent reviews of the program suggest that the current survey design is not providing data of the quality necessary to evaluate changes in fishery stocks (Whiteman, 2005; Pagan et al., 2004; Cummings et al., 2007). As a result, an evaluation of the SEAMAP-C sampling design has been proposed; suggested changes will be tested via future pilot studies (Cummings et al., 2007).

### *Results and Discussion*

Results provided here have been summarized from Whiteman (2005). For St. Croix the catch in both 1993–1994 and 2002 was dominated by coney (*C. fulvus*) and sand tilefish (*Malacanthus plumieri*), which represented 56% and 71% of the total catch biomass, respectively. Remainder of the catch differed for sampling years, with only 15 species common between years. Fish were classified as catch or bycatch depending on species and total or fork length. No significant change was noted in total trapped biomass classified as catch or bycatch between sampling years; however, in 1993–1994 bycatch was dominated by queen triggerfish (*Balistes vetula*) while in 2002 it was dominated by butterflyfish (*Chaetodon spp.*). Hook and line bycatch was dominated by *M. plumieri* in both sampling years. In St. John the catch in 1992–1993 and 1994–1995 was dominated by red hind (*E. guttatus*) and *B. vetula*, totaling 43–50% of total catch biomass. These two species also dominated the marketable total trapped biomass for the same years. However, by 1999–2000 *C. fulvus* comprised a greater proportion of total trapped biomass, while *E. guttatus* declined in total biomass from 29% to 16% in 1994–1995 and 1999–2000, respectively. *E. guttatus* and *B. vetula* also declined in capture frequency between 1992–1995 and 1999–2000. Total trapped biomass classified as bycatch increased from 5–6% to 12% for the same sample years and was dominated by butterflyfish (*Chaetodon* spp.; 1992–1993 and 1999–2000) and schoolmasters (*L. apodus*; 1994–1995). Hook and line biomass classified as bycatch has declined between 1992 and 2000, from 43% to 5%. This decline is attributable to a decrease in the total biomass of ocean triggerfish in the catch. These changes in catch composition appear to indicate changes within the target fish populations. On both islands the catch was dominated by small serranid species and throughout the sampling period there was no data to indicate change in the populations of larger species such as Nassau grouper. Further investigations into composition of catch classified as bycatch are warranted in order to determine the causes of the changes over time and ultimately the impacts of fishing on fishery resources (Whiteman, 2005).

## *NOAA CCMA-BB Fish Tagging Study*

A fish-tagging study was initiated by CCMA-BB in 2006 to track and monitor the movement and residency time of fishes within and across habitats in St. John, USVI. Resources within the VICRNM are poorly documented, its degree of connectivity to VINP is unknown, and over-exploitation has in part contributed to large changes in local reef fish assemblages. The VICRNM was established to provide full protection from resource exploitation; VINP has allowed resource harvest by artisanal fishers since 1956. In order to better understand habitat utilization patterns and movement of fishes among fished and unfished managed areas, an array of hydro-acoustic receivers was deployed and a variety of reef fish species were acoustically tagged. Objectives of this project are: 1) to track fish movements in the VINP and the VICRNM, and 2) to determine the degree of connectivity between the managed areas. Information on this project can be found at http://ccma.nos.noaa.gov/ecosystems/coralreef/acoustic_tracking.html.

### *Methods*

In July 2006, an array of nine hydroacoustic receivers with a detection range of about 350 m were deployed in Lameshur Bay. Sites were selected to allow overlap between nearby receivers in reefs and seagrass beds inshore and offshore of the reefs to allow detection of movement among habitats and between the VINP and the VICRNM. Simultaneously, 55 fishes were captured, tagged with VEMCO V9-2-L-R64K internal transmitters and released after 24 hours near the capture location. In April 2007, data on movement patterns of tagged fish were downloaded, an additional 21 receivers were deployed along 20 km of St. John's southern shoreline and 78 fishes were tagged (Figure 2.36).

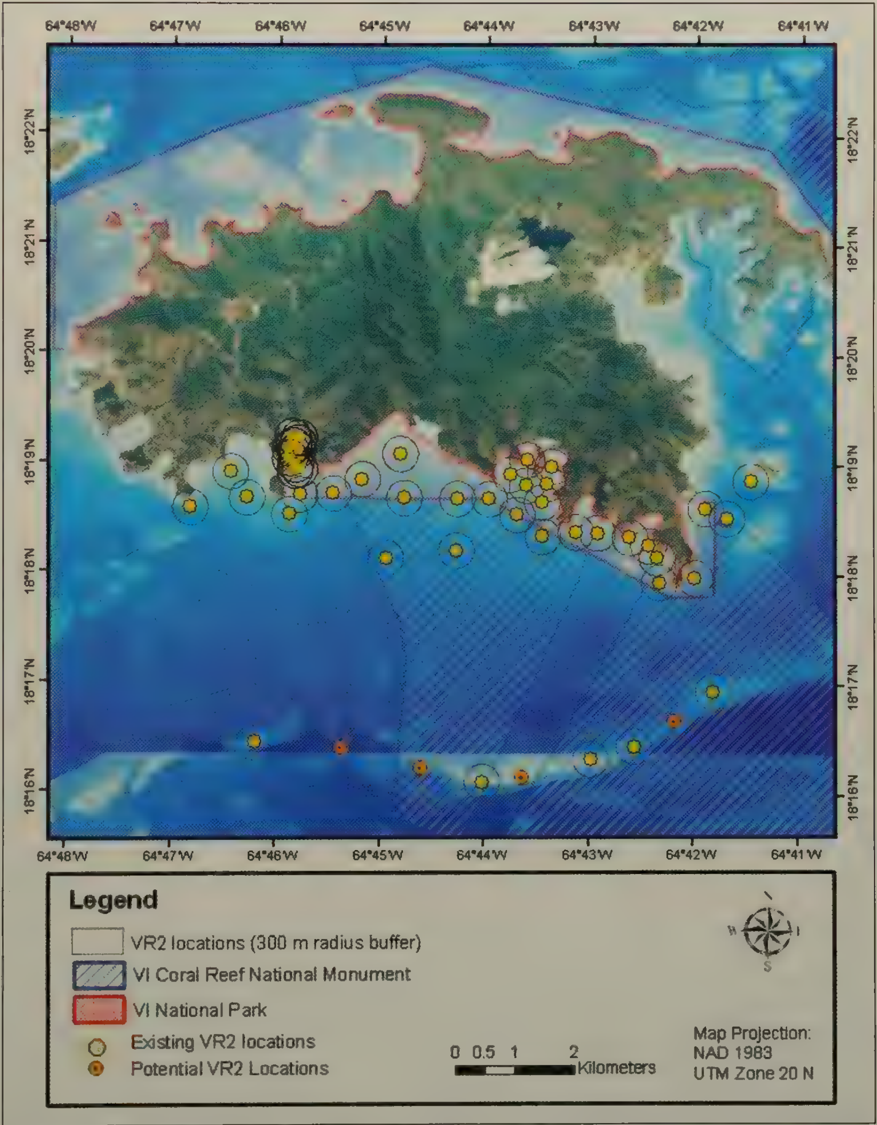


*Figure 2.36. Location of current and planned hydroacoustic receiver (VR2) array design to examine movement patterns of fishes inside and outside VINP, VICRNM and outside areas in St. John, USVI (n=40). Receivers have a 350 m radius detection buffer indicated by circles. Yellow spheres represent VR2s deployed by NMFS SEFSC for a conch movement study. Source: C. Jeffrey, NOAA CCMA-BB.*

*Results and Discussion*

A total of 123 fishes, representing 18 species and 10 families, were acoustically tagged in 2006 and 2007. Preliminary analysis of data from 55 fishes tagged in July 2006 indicates that lane snappers (*L. synargris*) and bluestriped grunts (*Haemulon sciurus*) showed diel movement from reef habitats during daytime hours to offshore seagrass beds at night. The timing of movement was highly predictable and coincided with sunrise and sunset over the course of the year. The data from 2006 also show that fish associated with reefs without adjacent seagrass beds made more extensive movements than fishes associated with reefs with adjacent seagrass habitats.

During July 2007, all 30 receivers were downloaded to recover the telemetry data for the 123 tagged fish. These data are currently being analyzed to determine broad-scale movement patterns and habitat use. Deployment of additional receivers (Figure 2.36) and continued analysis of telemetry information from fishes tagged in 2006 in Lameshur Bay is planned. Results of the study will allow resource managers to understand the movement of fish into and out of management units to identify resources that may require greater (or lesser) management focus and provide data necessary for the development of ecosystem management strategies for VIIS, VICRNM, and the Territory.

### SEAMAP-C Assessment of Conch Densities in Back reef Embayments on St. Croix

DPNR-DFW collected data on queen conch (*Strombus gigas*) densities, abundance and habitat preference in six shallow (1-7 m) back reef embayments on St. Croix. Surveys were conducted in three northeast bays from 1998 to 1999 and in three southeast bays from 2000 to 2001. Details of sampling methodology are provided in Mateo and Tobias (2001 and 2004) and Tobias (2005). Briefly, ten random two meter by 50 m belt transects were surveyed in each embayment. All conch encountered were counted and measured (total shell length). Data on habitat type was also recorded and percent habitat cover for each transect was estimated (Mateo and Tobias, 2001 and 2004).

*Results and Discussion*

Results provided here have been summarized from Tobias (2005). This was the first study of conch densities and distribution in St. Croix's shallow back reef embayments. Conch density (44 conch/ha over all six bays) from this study is higher than had been previously reported for St. Croix populations on the insular shelf platform (Wood and Olsen, 1983; Friedlander et al., 1994; Friedlander, 1997). A more recent study by Gordon (2002) documented significantly higher conch densities of 99.7 conch/ha for the insular shelf platform; this density is higher than found by any past studies or this study. The discrepancies may be attributable to several factors including patchiness of the resource and differences in survey methodology. Data from the current study suggest that conch densities in these bays are not sufficient to maintain inshore populations, based on research by Stoner and Ray (1996) who reported that densities of <53 adult conch/ha can adversely affect reproduction. Mean conch size observed across all bays was 17.1 cm, and 87% of surveyed conch were under the legal size limit (22.8 cm). Of the five habitat types identified in the bays (seagrass, algal plain, patch reef, sand and rubble), a total of 98% of recorded conch (79% of those <22.8 cm and 63% of those ≥22.8 cm) were found in seagrass, algal plain or sand (or combination of these habitats). This data suggest the importance of these back reef embayments as nursery areas for St. Croix conch populations. It is likely that conch in these habitats are heavily impacted by recreational take as evidenced by extensive shell middens on adjacent shorelines. Upon implementation of park rules and regulations, baseline information from this study can be used to evaluate park effectiveness in protecting and facilitating the recovery of these conch populations.

### Assessment and Monitoring of Spiny Lobster Populations at BIRNM, St. Croix, USVI

Florida Fish and Wildlife Conservation Commission (FWC) was contracted by the NPS to document lobster resources in BIRNM and to determine the effectiveness of the reserve for Caribbean spiny lobsters (*Panulirus argus*). The sampling protocol was designed to test the hypothesis that lobsters in the reserve will be larger and more abundant than those found in the surrounding fishery. Outside the reserve, lobsters are harvested year-round, typically by divers. The minimum legal harvest size is 3.5” (89mm) carapace length (CL).

*Methods*

Preliminary lobster surveys were conducted in BIRMN in April 2004. In June 2004, lobsters were surveyed both in the reserve and in the surrounding fishery (limited to adjacent waters comprising the northern portion of the EEMP). Yearly surveys have been conducted in both the reserve and surrounding fishery during April since that time. Sixty-minute timed surveys are used to estimate the relative abundance of lobsters. Surveys are conducted by teams of two divers who count and attempt to catch all lobsters encountered within the survey time frame. Capture time is not included in order to standardize search time. For a complete description of methods see Cox and Hunt (2005). Sampling is stratified by habitat type in the BIRNM reserve and surrounding fished area. Habitats include: Deep Reef (spur-and-groove reef on the shelf slope); Western Ledges (high relief ledges inside the northwest border of BIRNM; Linear Reef (slope of the fringing reef from 15-40’ depth); Back Reef; Patch Reefs (isolated patch reefs surrounded by sand halos and seagrass); and Nearshore Patch Reefs (rubble/hardbottom patches in Teague Bay outside BIRNM).

*Results and Discussion*

Despite implementation of no-take rules in the expanded reserve in 2003, active fish traps were found in the reserve in both April and June of 2004. The new reserve boundaries were marked and enforced beginning in 2005. Since that time, fish traps have not been recorded within the reserve. Two additional species, *P. guttatus* and *P. laevicauda*, have been documented in the BIRNM reserve. An additional species, *Justitia longimanus* was found in the adjacent fishery. Recruitment of Caribbean spiny lobsters in BIRNM appears to be limited not by larval influx but by appropriate settlement habitat. Post-larval settlement on artificial collectors placed in the lagoon surrounding Buck Island was similar to or greater than settlement on collectors in the Florida Keys for the period April 2004–April 2005 (Figure 2.37). Thus far, the only high-quality larval lobster settlement habitat observed has been on algal-covered patch reefs located outside of the reserve in Teague Bay on the northeastern shore of St. Croix.

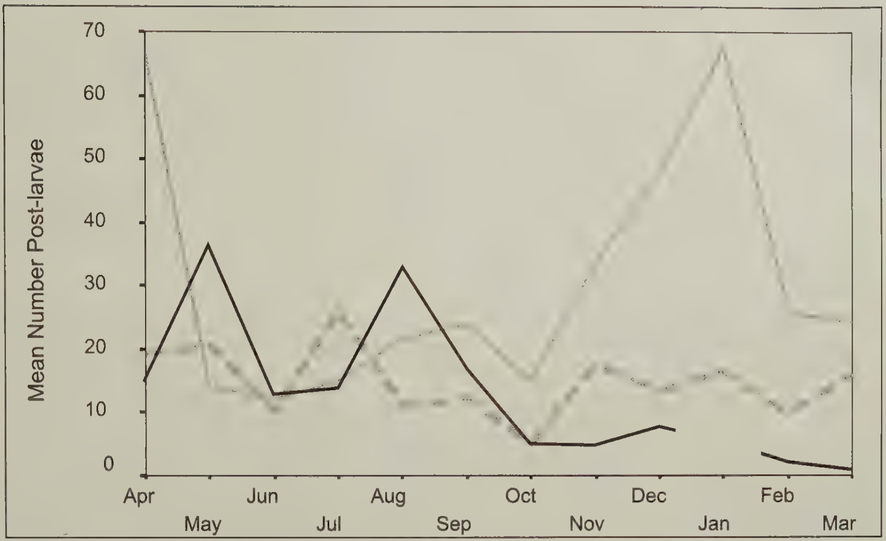


*Figure 2.37. Post-larval lobster settlement on collectors at BIRNM (black) compared with collectors in the Florida Keys (gray), April 2004-March 2005.*

There are significantly more legal-sized (CL ≥89 mm) spiny lobsters inside the BIRNM reserve than in the surrounding fishery. Additionally, an increase in the abundance of legal-sized lobsters has been documented inside the reserve since the installation of boundary buoys in 2005 (Figure 2.38). There was no significant difference in the mean size of legal-sized lobsters in the reserve or the fishery in our first three sampling periods (Figure 2.38). In 2006, however, just one year after boundary markers were installed, legal-size lobsters in BIRNM were significantly larger than those in the fishery. As in the Florida Keys Western Sambo Ecological Reserve, the largest lobsters in the reserve are found on patch reefs (Cox and Hunt, 2005). The documented increase in size and abundance of lobsters in the reserve relative to lobsters in the surrounding fishery is evidence that BIRNM may become an effective reserve for spiny lobsters. FWC and NPS will continue to monitor spiny lobsters in and around BIRNM to assess reserve efficacy over the long term. It is essential to continue effective protection for park resources through signage, law enforcement patrols and education.

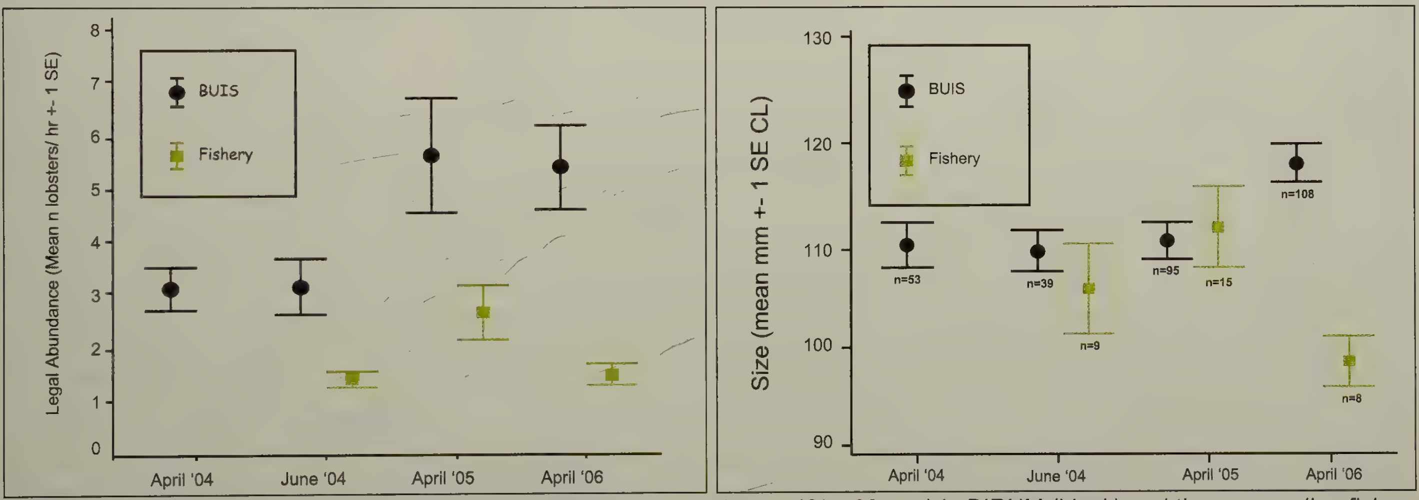


*Figure 2.38. Abundance (left) and size (right) of legal-sized spiny lobsters (CL ≥89 mm) in BIRNM (black) and the surrounding fishery (green), April 2004-2006. C.Cox, unpub. data.*

### *UVI-CMES Monitoring of Spawning Aggregations*

In the late 1970s and early 1980s, unregulated fishing on grouper spawning aggregation (SPAG) sites throughout the USVI led to the extirpation of Nassau grouper (*E. striatus*) and brought the red hind (*E. guttatus*) population to the verge of collapse (Olsen and LaPlace 1978; Beets and Friedlander, 1992). Based on recommendations from the CFMC in 1990 an important red hind SPAG, the Red Hind Bank, 12 km south of St. Thomas was closed during the spawning season from December through February each year. In 1995, another red hind SPAG on Lang Bank, 16 km east of St. Croix, and a mutton snapper (*L. analis*) SPAG south of St. Croix were also closed during the respective spawning seasons. Determined to be critical habitat for reef fishes, and in particular red hind reproduction, an area encompassing 41 km$^2$ including the Red Hind Bank was closed to fishing year-round beginning in 1999, establishing the Red Hind Bank Marine Conservation District (MCD) as the first no-take federal fishery reserve in the USVI. Another small deep reef south of St. Thomas, the Grammanik Bank (Figure 2.39) also traditionally hosted SPAGs of yellowfin (*Mycteroperca venenosa*) and Nassau grouper (*E. striatus*). During 2000 and 2001, an estimated 20,000 pounds of yellowfin grouper was harvested by fishers from the Grammanik Bank, prompting the CFMC to call an emergency closure of the bank from March through May 2004, the grouper spawning season. In 2005 a 0.75 km$^2$ area surrounding the bank was closed permanently to trap fishing, and closed to all fishing except for highly migratory species from February 1 through April 30 each year.

A comprehensive SPAG monitoring effort was initiated by the UVI-CMES in the MCD in 1999 (Nemeth, 2005) and on the Grammanik Bank in 2003 (Nemeth et al., 2004a; Kadison et al., 2007). Red hind monitoring was extended to Lang Bank, St. Croix for two years in 2004 and 2005 (Nemeth et al., 2006a; Nemeth et al., 2007).

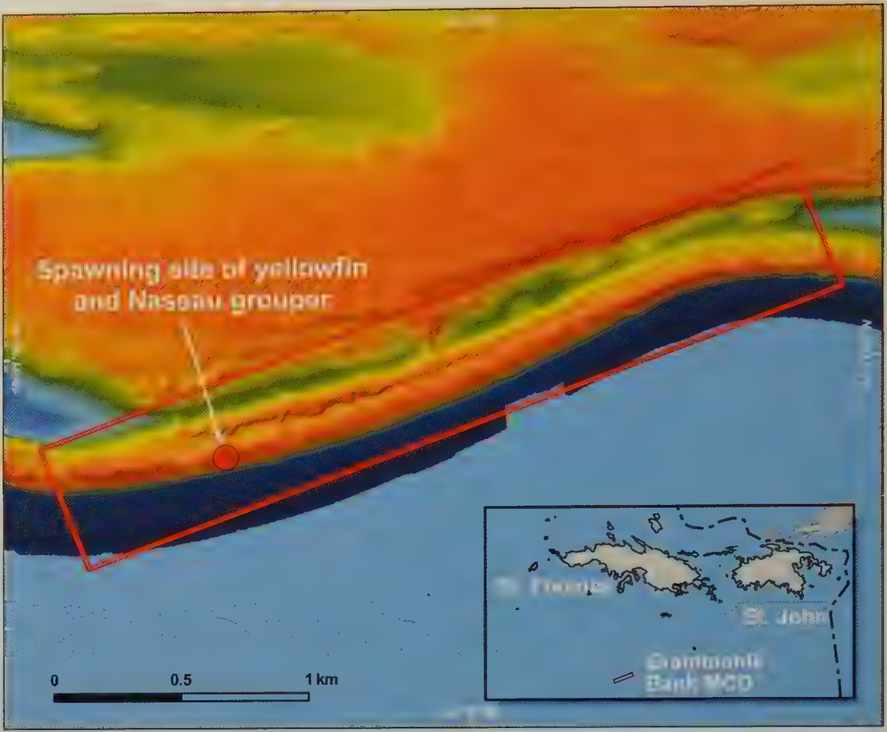


Figure 2.39. Yellowfin and Nassau grouper form spawning aggregations at sites on Grammanik Bank. Source: E. Kadison, UVI-CMES; Map: K. Buja.

*Methods*

The methodology used by CMES to determine SPAG site boundaries and spawning population characteristics are outlined in Nemeth (2005). SCUBA surveys and fish traps are used to determine fish densities, size distributions and aggregation temporal dynamics. Ultrasound imaging (Whiteman et al., 2003) is used to determine the gender of fish. A tag/recapture program using external dart or t-tags has been conducted since 2002 to help determine fish migration patterns across the insular shelves (Nemeth, 2005). An additional migration study focused on movement patterns of fish in and out of the protected aggregation areas was initiated in 2007. Hydro-acoustic tags were surgically implanted in red hind, Nassau grouper and yellowfin grouper during the spawning season and receivers were placed along the insular shelf edge and around fishery closure area boundaries. Data currently being collected will help determine if the MCD and Grammanik Bank closures are adequate in size and location to protect the spawning fish while on the aggregation sites.

*Results and Discussion*

Hind Bank MCD and Lang Bank

A total of over 3,000 red hind have been collected and tagged on the MCD since 1999 and approximately 1,000 fish have been tagged on Lang Bank. The MCD red hind aggregation is the first reported recovery of a SPAG (Nemeth, 2005), with an estimated spawning population of over 84,000 fish and improved regional fisheries (St. Thomas/St. John) associated with the establishment of the year-round closure. Although Lang Bank was also closed to fishing during the spawning season (December through February) the SPAG has not fared as well since seasonal protection beginning in 1995. Red hind from the St. Thomas MCD aggregation were significantly larger (38.0 versus 32.5 cm TL) and nearly nine times more abundant in a comparative study (Nemeth et al., 2006a). This may be due to inappropriate placement of closure boundaries, seasonal versus year round protection or lack of enforcement on Lang Bank. Port sample surveys of red hind length also show that red hind are significantly larger in St. Thomas. Movement patterns, temporal and spatial changes in sex ratios and annual and lunar predictability appear similar between aggregations in the MCD and Lang Bank (Nemeth et al., 2007). Red hind SPAGs occur after the winter solstice (December 20) and before February 20, showing a distinctive peak from 20-40 days after the winter solstice. Spawning typically occurs in declining seawater temperature, between the range of 26-27.5 °C (Nemeth et al., 2007). Males arrive earlier to the spawning site than females, swimming from west to east at both sites, and appear to stay longer before returning to their home territories. Other species have been observed aggregating in the MCD including tiger grouper (*M. tigris*), mutton snapper (*L. analis*) and schoolmaster snapper (*L. apodus*). On Lang Bank, large numbers of queen triggerfish (*B. vetula*) were observed around the full moons in January and February 2005.

Grammanik Bank

Since monitoring began in 2004, over 450 Nassau and 500 yellowfin grouper have been collected and tagged on the Grammanik Bank during the months of February, March and April (Table 2.8). Fish begin aggregating a few days before the full moon across the 1.5 km bank and spawn seven to 10 days after the full moon (Nemeth, unpub. data). Size is not significantly different between sexes in Nassau grouper and ranges from 42.7 to 84.6 cm TL with a mean of 61.9 cm TL. Male yellowfin grouper are signifi-

*Table 2.8. Number of Nassau grouper and yellowfin grouper collected from 2004 to 2007 by year.*

| | NASSAU GROUPER | | YELLOWFIN GROUPER | |
|---|---|---|---|---|
| **Year** | **n** | **Sex ratio M:F** | **n** | **Sex ratio M:F** |
| 2004 | 63 | 0.43:1.00 | 28 | 1.15:1.00 |
| 2005 | 116 | 0.68:1.00 | 42 | 1.80:1.00 |
| 2006 | 185 | 0.85:1.00 | 244 | 1.46:1.00 |
| 2007 | 87 | 0.62:1.00 | 186 | 1.56:1.00 |
| **Total** | **470** | **0.69:1.00** | **501** | **1.53:1.00** |

cantly larger than females, with mean sizes of 77.9 cm TL and 70.0 cm TL respectively, suggesting a protogynous hermaphroditic life history. Sex ratios of Nassau grouper and yellowfin grouper on SPAGs have shown consistent trends on a yearly basis from 2004 to 2007 (Table 2.8) averaging 0.69:1 (M:F) for Nassau grouper and 1.53:1 for yellowfin grouper. Aggregations of yellowfin mixed with Nassau grouper have been observed over the southwest corner of the Grammanik Bank between four and seven days after the full moon. These aggregations ranged in size of from 20 to 1,000 individuals. Yellowfin spawning was observed six to nine days after the full moon in March and April 2007. Although groups of Nassau grouper have been observed within the yellowfin grouper aggregation demonstrating pre-spawning behavior and coloration, they have not been observed spawning. Based on visual surveys the estimated spawning population size of yellowfin grouper and Nassau grouper on the Grammanik Bank is 1,000 and 200 fish respectively. Several other species have been observed on the bank either spawning or in very large aggregations. Approximately 200 tiger grouper (*M. tigris*) were observed spawning on the bank in February 2004, with harems made up of one male spawning with one to four females (Kadison, unpub. data). Cubera snapper (*L. cyanopterus*) have been observed on the bank annually from May through August since 2003 in aggregations of up to 600 fish, and dog snapper (*L. jocu*) have been observed in aggregations of close to 1000 fish in February and March, exhibiting pre-spawning behavior and releasing clouds of sperm (Kadison et al., 2007). In March 2007 an aggregation of over 100 mutton snapper was seen over the sand channel adjacent to the Grammanik Bank. In addition to these reef fishes, schools of hundreds to thousands of horse-eye jacks (*Caranx latus*) and cero mackerel (*Scomberomorus regalis*) are regularly observed during March and April over the bank, further highlighting the importance of the reef as a multi-species aggregation area.

## CURRENT CONSERVATION MANAGEMENT ACTIVITIES

The previous USVI State of the Reefs report (2005) provided an overview of the federal and territorial agencies with jurisdictional control of submerged lands in the USVI. These agencies continue to conduct research and monitoring activities into local coral reef ecosystems. Additionally, many non-governmental agencies are contributing to efforts to increase the effective management of these important marine resources.

### Marine Protected Areas

While Marine Protected Areas (MPAs) in the USVI were included in the last report (Jeffrey et al., 2005), the USVI's system of Areas of Particular Concern (APC) were not discussed. In 1978, 18 APCs were identified and designated (Figure 2.40), and in 1994 they were established by law (Bill No. 20-0252). Most APCs have a significant marine component; analytical studies have been completed for all APCs and several have draft management plans. To date, none of the analytical studies or management plans have been adopted by the Territorial government, which manages the APC system. As a result, the APC designation cannot be used as a regulatory or planning tool. However, three of the APCs have active resource use management activities occurring within them; not including the St. Croix EEMP, which comprises portions of four APCs (see below). Sandy Point is a National Wildlife Refuge managed by the U.S. Fish and Wildlife Service, a portion of the Southgate Pond APC is owned and managed by the St. Croix Environmental Association (SEA), and the beach portion of the Magens Bay APC is managed by the Magens Bay Authority.

A new MPA was established in 2005 to protect a deep reef south of St. Thomas that serves as a spawning ground for several important commercial fish species. The Grammanik Bank Seasonally Closed Area is managed by NOAA through the CFMC. The area is closed to all fishing from February 1st to April 30th annually. During the rest of the year the use of fish traps, pots, bottom long lines, gill and trammel nets are banned within the closure area.

### St. Croix East End Marine Park

As discussed in the 2005 chapter, the St. Croix East End Marine Park (EEMP) was established in 2003 when the Governor of the Virgin Islands signed Act 6572 into law. The EEMP represents the culmination of 40 years of vision (incorporates portions of four APCs) and several years of collaboration to establish a marine park for St. Croix. The park is managed through DPNR-CZM and to date has been supported entirely through federal funds. The EEMP is designed to be a multi-use park that spans approximately 60 mi$^2$ divided among four management zones: open fishing area, recreation area, turtle wildlife area and no-take area (Figure 2.40). The EEMP has been a mechanism for the USVI to implement Local Action Strategy initiatives and is a first step toward a territorial marine park system. Since the 2005 edition of this report, draft rules and regulations and a sustainable funding strategy were completed and a system of 55 day-use moorings was installed. Park rules and regulations were drafted by DPNR-CZM with extensive input from the EEMP Advisory Committee, stakeholders and the general public. The draft rules and regulations were approved by the CZM Commission in April of 2006 and are currently awaiting final approval by the VI Government. Several additional programs have been initiated including, but not limited to, the development of an education and outreach program, installation of boundary and zoning markers, installation of signage, completion of a vessel use survey and development of a watershed and coastal wetlands protection plan. Complete information on park programs is presented on the park's Web site (http://www.stxeastendmarinepark.org).

In December 2006, DPNR-CZM and CCMA-BB collaborated on a week-long, on-site training mission to develop a biological monitoring program for the park. CCMA-BB staff assisted in the identification of appropriate program goals and objectives and the development of a sampling regime to meet them. CCMA-BB staff also provided field training in the use of the NOAA monitoring protocols. Implementation of the new regime is planned to coincide with and complement the future scheduled missions of CCMA-BB to assess the adjacent waters of the BIRNM.

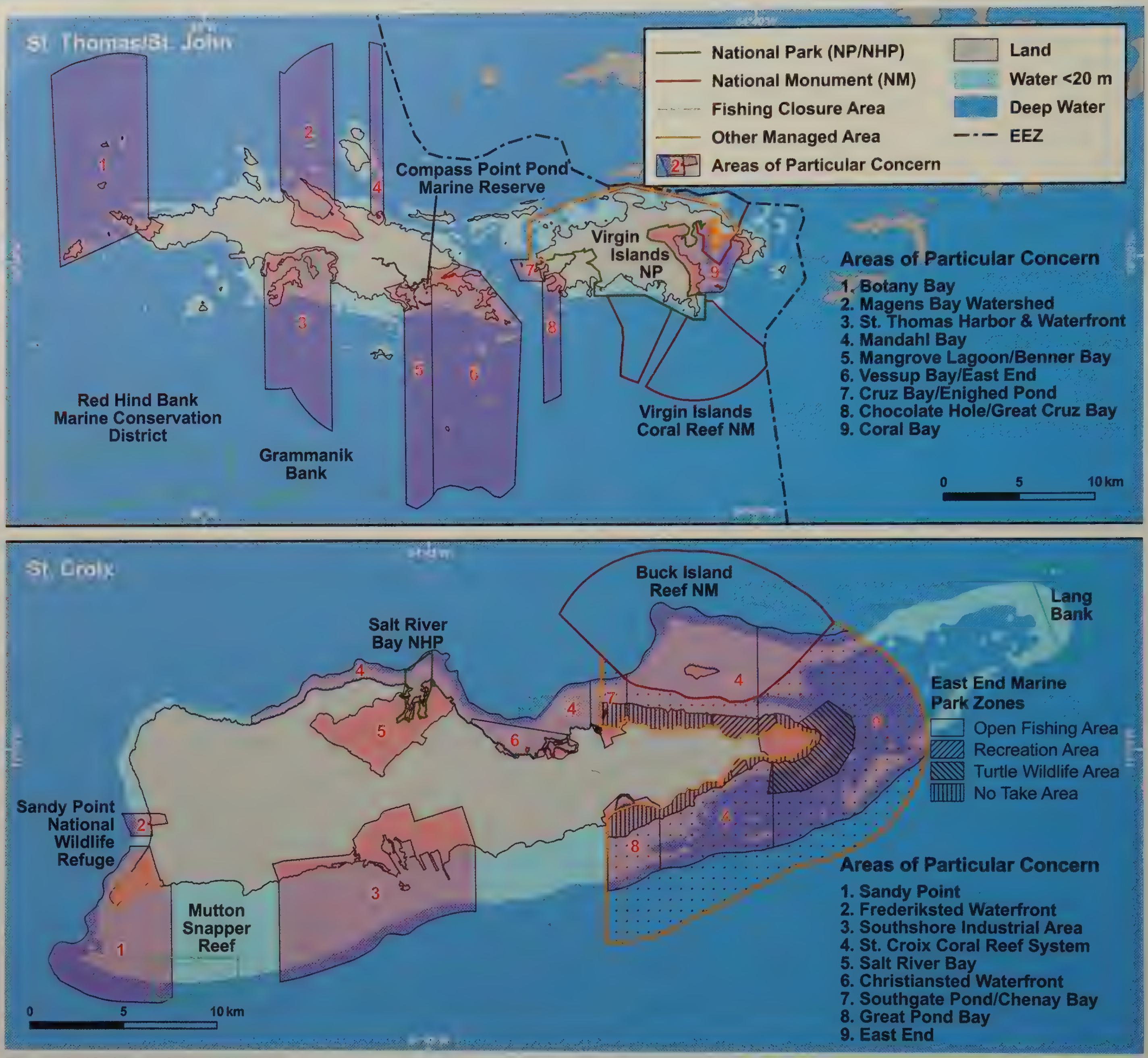

St. Thomas/St. John
National Park (NP/NHP)
National Monument (NM)
Fishing Closure Area
Other Managed Area
Areas of Particular Concern
Land
Water <20 m
Deep Water
EEZ
Compass Point Pond Marine Reserve
Virgin Islands NP
Red Hind Bank Marine Conservation District
Grammanik Bank
Virgin Islands Coral Reef NM
Areas of Particular Concern
1. Botany Bay
2. Magens Bay Watershed
3. St. Thomas Harbor & Waterfront
4. Mandahl Bay
5. Mangrove Lagoon/Benner Bay
6. Vessup Bay/East End
7. Cruz Bay/Enighed Pond
8. Chocolate Hole/Great Cruz Bay
9. Coral Bay
1
2
3
4
5
6
7
8
9
0
5
10 km
St. Croix
Buck Island Reef NM
Lang Bank
Salt River Bay NHP
East End Marine Park Zones
Open Fishing Area
Recreation Area
Turtle Wildlife Area
No Take Area
Sandy Point National Wildlife Refuge
Mutton Snapper Reef
Areas of Particular Concern
1. Sandy Point
2. Frederiksted Waterfront
3. Southshore Industrial Area
4. St. Croix Coral Reef System
5. Salt River Bay
6. Christiansted Waterfront
7. Southgate Pond/Chenay Bay
8. Great Pond Bay
9. East End
1
2
3
4
5
6
7
8
9
0
5
10 km

*Figure 2.40. Map of the USVI showing managed areas mentioned in this chapter. Map: K. Buja.*

## Territorial MPA System Initiative

In addition to creating the EEMP, Act 6572 authorized the establishment of a territorial system of marine protected areas. Two non-governmental organizations, OC and TNC, have partnered with DPNR-CZM to further the development of the territorial MPA initiative. The USVI offices of OC and TNC are implementing two complementary territorial marine protected area system projects. Both projects rely on and encourage community participation.

OC's project titled, "Assessment of the Marine Protected Areas of the U.S. Virgin Islands as Part of a Functionally Integrated Network" entails assessing the ecological, legislative and socioeconomic status of territorial MPAs. A thorough assessment of the socioeconomic value and potential of the MPAs as individual units will allow managers to gain an understanding of how park units will function when integrated into a territorial network. Assessments will be conducted through review of available data, maps, statistical reports, regulations, and primary sources derived from focus groups, semi-structured interviews, structured surveys and observations. Planning for surveys and data collection will be done in consultation with fishing community representatives and other stakeholders and experts.

The TNC project, "Bridging Gaps for a Territorial Marine Park System in the U.S. Virgin Islands," will incorporate the results of the assessments completed by OC into decision-making tools using MARXAN software. Priority conservation targets will be assessed and threats to the targets evaluated and ranked. Results will be used to inform the design of a territorial MPA network based on conservation goals and existing threats, while incorporating concepts of ecological and social resilience. The design options will help identify management priorities in existing MPAs and areas that could be added to the network. Detailed ecological profiles of MPAs and socioeconomic considerations combined with a threat based analysis will help elucidate the functional role that each MPA plays, or could play, within a territorial park system.

### Resource Management Trainings/Workshops

Since the last report, there has been a serious effort to increase management effectiveness, leverage resources, increase inter-agency collaboration, share data products and build local resource management capacity. Several workshops and trainings have been held to achieve these goals by providing instruction in various management tools, identifying gaps in resource monitoring and introducing new tools for data management and sharing. These efforts are summarized below.

### Caribbean Workshop on MPA Effectiveness and Adaptive Management

This workshop, held by NOAA, TNC and OC in May 2005 on St. Croix, strengthened efforts to develop and improve management plans in selected Caribbean MPAs. The workshop was designed to build interest, momentum, and capacity for Caribbean-based marine managers and conservation practitioners to adaptively manage MPAs in the region. The workshop introduced and made use of the IUCN guidebook, *How is your MPA doing?* (Pomeroy et al., 2004) as a way to introduce managers to the rationale for evaluating MPA management effectiveness and a process for selecting indicators, completing an evaluation, and using results for adaptive management. Through hands-on use of this tool, managers were encouraged to strengthen existing MPA management plans and develop new plans that logically and inherently encourage adaptive management by identifying clear and appropriate goals, objectives, and management strategies. Participants included MPA managers and leaders from the USVI, Puerto Rico, the BVI, Grenada, The Bahamas and Bonaire. Each jurisdiction worked as a group throughout the workshop and focused on priority MPA sites for which they defined and strengthened MPA goals and objectives, developed management actions to achieve these objectives, and selected appropriate effectiveness indicators to be measured at each site and incorporated into ongoing monitoring efforts.

### Workshop on Satellite Remote Sensing Tools for Monitoring Thermal Stress Leading to Coral Bleaching

This workshop, sponsored by NOAA's Coral Reef Watch Program, was held in January 2006 on St. Croix partly in response to the mass coral bleaching event of 2005. A major goal of the workshop included building local management capacity through the introduction of various remote sensing tools to detect environmental conditions that lead to coral stress. Participants included federal and local resource managers and scientists from the BVI, Puerto Rico and the USVI. In addition to in-depth discussion of Coral Reef Watch satellite bleaching products, participants made presentations on the various responses to the 2005 bleaching event. Dialogue included methods of response, findings, gaps, needs, monitoring approaches and ways to improve collaboration. Participants also discussed how responses could be improved in the event of a future bleaching event.

### Vital Signs Indicator Development Workshops

The NPS SFCN is one of 32 NPS Inventory and Monitoring Program networks, whose responsibility it is to acquire the information and expertise needed by park managers to maintain the integrity of the ecosystems within their park units. In order to achieve this goal the SFCN held a series of Vital Signs Indicator Development Workshops early in 2006. Vital Signs are physical, chemical, and biological elements and processes of park ecosystems that represent the overall health or condition of the park (SFCN Vital Signs Fact Sheet). These workshops were attended by 70 scientists, agency staff, NPS staff and non-NPS natural resource managers. The process resulted in a list of 62 indicators ranked for importance to each park unit within the SFCN. The development of monitoring plans for selected vital signs indicators is ongoing.

### Conservation Planning Training

Over 25 DPNR, USDA, UVI and local nonprofit staff members participated in an Area-Wide Conservation Planning Training workshop held May 23-25, 2006 at the UVI St. Croix Campus. The training was conducted by USDA Natural Resources Conservation Service (NRCS) trainers and hosted by the Virgin Islands Resource Conservation & Development Council, Inc. (VI RC&D), in cooperation with DPNR-CZM and the SEA. The training was sponsored in support of the USVI Land-Based Sources of Pollution Local Action Strategy and was designed to help build USVI technical capacity in order to improve the watershed planning process. The training featured a hands-on approach to watershed planning through the use of a local case study at Southgate Pond. Participants learned about the importance of the planning process and identifying a good cross-section of stakeholders; collecting and analyzing data and information for the area; and developing Inventory and Implementation Action Plans and an Evaluation and Monitoring Plan.

### Workshop on Managing Watersheds and Stormwater Runoff in the USVI

In August 2006, DPNR-CZM hosted a three day Watershed Planning Workshop to improve territorial stormwater management, watershed planning and coral reef protection. With the assistance of NOAA, experts from the Center for Watershed Protection (CWP) designed the workshop using territory-specific regulatory and programmatic parameters. Workshop participants included DPNR technical staff from DEP, Energy, Historic Preservation, Building Permits, DFW, Comprehensive and Coastal Zone Planning, and CZM. Content and activities were structured to increase agency-wide watershed-based planning and resource management capacity. Outcomes from the workshop included a report of findings and recommendations for strengthening existing program effectiveness and catalyzing DPNR's watershed management efforts, as well as a watershed management plan and demonstration project for Coral Bay, St. John. This collaborative watershed management project between DPNR, CWP, EPA, USDA-NRCS and the Coral Bay Community Council has provided a mechanism for leveraging of funds and technical capacity to improve stormwater management techniques in upland watersheds thereby protecting offshore coral reefs.

### U.S. Caribbean Comprehensive Coral Reef Ecosystem Monitoring Project (C-CCREMP) Workshop

C-CCREMP is a project funded by NOAA's Coral Reef Conservation Program (CRCP) that is exploring the expansion and integration of current coral reef ecosystem monitoring activities into a comprehensive long-term regional assessment and monitoring program involving federal agencies, academia, local resource marine management agencies, and other partners in the U.S. Caribbean. In September of 2006, CCMA-BB and Southeast Fisheries Science Center held workshops in La Parguera, PR and St. Thomas, USVI to strengthen collaboration among local scientists and managers and to investigate the feasibility of conducting periodic comprehensive monitoring activities in the U.S. Caribbean islands using consistent characterization and assessment methods. The workshops were intended to introduce the project to partners and solicit input from the scientific and management community. To further support regional collaboration, NOAA placed a staff member in the USVI in 2007 to improve coordination projects and support other CRCP coral reef ecosystem monitoring activities.

### 16th U.S. Coral Reef Task Force Meeting (USCRTF)

The 16th Meeting of the USCRTF was held in St. Thomas in October 2006. Issues facing U.S. Caribbean reefs were a priority at the business meeting and many of the associated workshops. The Status of USVI Coral Reef Ecosystems workshop aimed to provide basic information on the health of USVI reefs to local policy and decision makers, as well as their federal counterparts. The workshop's objective was to engage in a solution-oriented discussion about USVI's coral reefs and consisted of a series of presentations by local managers and scientists, followed by panel discussions. Workshop outcomes were reported to CRTF members during the business meeting session on Caribbean Coral Reefs and included: development of a coral strategy for the USVI; training and assistance in conducting effectiveness assessments to achieve adaptive management of reefs; and replication of the workshop to targeted audiences (Rothenberger, 2006). Workshop outcomes were supported by the VI Government and resulted in a CRTF resolution (#16.10) to support the USVI Government, through DPNR-CZM, in the review, analysis, development, and implementation of responses to workshop recommendations. Other resolutions of particular importance to the USVI included those to address coral disease issues and development and implementation of response plans to coral bleaching (http://www.coralreef.org).

### Gear Bans

Gill nets are large mesh nets that catch finfish by entangling their gills. The nets catch indiscriminately by entangling anything that cannot fit through the mesh, resulting in the take of unwanted and untargeted species including reef invertebrates, sea turtles and birds. Net fishing can also impact coral habitats directly through interaction of gear with benthic communities. Indirect impacts of net fishing may be of even greater consequence for USVI coral reef ecosystems. By placing nets along daily migration routes, the USVI gill net fishery selectively targets large herbivores such as parrotfish and surgeonfish, which play an important ecological role in coral reef ecosystems. Their removal through overfishing has been linked to shifts from coral to algal-dominated communities.

Net fishing is a fairly new technique in the USVI that began in the 1990s as a result of declining catch rates of traps and other gear types during a prolonged economic recession on St. Croix. Gear loss due to hurricane impacts and gear bans in other jurisdictions (e.g., Florida) also contributed to increasing use of gill nets. After Florida's net ban in 1994, gear suppliers began promoting their equipment in the USVI. Net fishing now accounts for a greater proportion of annual landings on St. Croix than traditional fishing gear (Toller and Tobias, 2005).

A proposed gill net ban originated when a St. Croix gill netter voiced concerns about gill net overfishing. A subsequent 2001 DPNR VI commercial fisher opinion survey identified excessive catch by fishers using gill and trammel nets as a problem requiring regulation. Local dive operators expressed concerns that overfishing and continued use of gill nets could have serious impacts on the St. Croix fishing industry as well as on dive tourism. DPNR data shows that average fish size on St. Croix is consistently smaller than on St. Thomas, where little gill netting takes place. The proposed ban was widely supported and recommended by both the St. Croix Fishery Advisory Committee and DFW in a paper presented at the 58th Annual Meeting of the Gulf and Caribbean Institute (Toller and Tobias, 2005). DFW sought and received a $70,000 grant to compensate fishers displaced by the ban. In July 2006, gill-net fishing was banned in the USVI when Governor Charles Turnbull signed into law a revision of Title 12, Chapter 9A, Section 321-1 of the VI Code. However, to date the ban has not been enforced, and DFW funds to compensate affected fishers were never distributed.

## OVERALL CONCLUSIONS AND RECOMMENDATIONS

Coral reef ecosystems in the USVI continue to be threatened by a number of natural and anthropogenic stressors. There are multiple causes for declining coral reef health in the USVI. Arguments can be made that coral reef health is declining due to ineffective natural resource management, inadequate land use planning, exploitation of resources, or natural events (hurricanes or increasing SSTs). The continued decline of territorial coral reef health is exacerbated by a lack of critical data and institutional limitations to address the anthropogenic stressors known to adversely affect these ecosystems. The challenge for coastal communities, and the USVI in particular, will be to recognize the economic, cultural, and scientific value of coral reefs, and to create and implement a community-based vision for their conservation.

Recent assessments of territorial coastal water quality indicate that while it continues to be generally good, there have been declines since the last report (Jeffrey et al., 2005). This decline is in part attributable to nonpoint source pollution from development-induced erosion, sedimentation and poorly maintained septic systems. Point sources of pollution such as inadequate wastewater and solid waste treatment and disposal also contribute to the territory's declining water quality. While all of these sources contribute to the deterioration of coral reef health, it is unknown if and how corals affected by pollution are more vulnerable to additional stressors such as increasing SSTs or disease.

Unfortunately, despite indications of the potential resiliency of territorial reefs at some locations, coral reefs in the USVI were severely impacted by the 2005 bleaching event and subsequent disease outbreaks. Prior to this major bleaching/disease event, three of six study sites monitored by NPS SFCN (two in VINP, one in BIRNM) showed statistically significant increases in coral cover (Miller et al., 2005). These gains were short-lived; subsequent surveys revealed the devastating consequences of elevated seawater temperature and their effects on coral reefs. Ultimately, the loss of over half of the remaining live coral cover on reefs highlight their vulnerability to the unprecedented amount of natural and anthropogenic stressors found in the territory. The effect of these losses and potential impacts on the wider ecosystem, including populations of ecologically and commercially important fish and invertebrates, as well as the ecosystem services they provide may not be known for years or decades.

The considerable response to the bleaching event provided significant insight into the scope and impacts of the event. However, the bleaching event also made it clear that the USVI coral monitoring community was largely unprepared to respond to such a large-scale and temporally restricted event. The response strained agency resources, and it's unclear whether such a response could have been repeated if the USVI experienced a similar event in 2006. It has also become clear that the information needed to mitigate such events is incomplete. It is unknown how the effects of the bleaching event and subsequent disease-related mortality will impact USVI reefs in the future. Questions remain as to whether surviving corals are more resilient to these types of occurrences, or if surviving the 2005 event has weakened them so that they will not be able to withstand the next. Long-term impacts on coral reproduction are unknown. More research is needed into the process of bleaching and disease, particularly into synergistic effects of these processes. Additionally, baseline information on coral diseases and their impacts on USVI coral reefs is lacking. This information is critical to effectively manage and respond to these types of events. Without it, the ability of managers to address compounding factors within their control, thereby potentially mitigating the impacts of such events, is impaired.

Obtaining information on reef fisheries remains a challenge for resource managers in the USVI. Data on fishing effort and catch from the commercial fishery are scarce because of inconsistent and incomplete reporting by fishers (SEDAR 14, 2007). Likewise, very few data are available on recreational harvest of reef fishes, although recreational fishing is considered an important source of fishing mortality in the territory. A recent review of fisheries data from the USVI by NOAA concluded that available data collected from fishery dependent and independent surveys were inadequate for determining the status of queen conch, mutton snapper and yellowfin grouper fisheries. Nevertheless, existing data indicate that catch composition continues to be dominated by herbivorous fishes (e.g., small parrotfishes) rather than the large snappers and groupers that dominated commercial reef fish catch forty years ago (Jeffrey et al., 2005). Additionally, incompatibility between some federal and territorial fishery regulations and inter-island differences in permitted gear types (e.g., trap mesh size) complicates reef fish management by making enforcement of existing regulations more difficult. Data from fishery-independent surveys in shallow, nearshore environments are more available but may not reflect the status of fished populations in deeper offshore waters. Data from such studies indicate that federal and territorial marine protected areas and seasonal closures may be increasing the abundance, size, and spawning activity of some targeted species (e.g., queen conch, red hind and Nassau grouper).

Stressors affecting USVI reefs are cumulative in nature. Rising SSTs, sedimentation, pollutants, storms, fishing and disease all act in concert to compromise coral condition and resiliency. In order to begin proactive, effective management of our reefs, it is imperative to focus regulatory and management efforts on stressors that can be locally controlled (i.e., mitigating sedimentation through better land use planning and practice, mitigating pollutants through reduction of sewage bypasses, etc). In order to accomplish this, maintaining and restoring coral reef ecosystem health must become a priority for the USVI community.

## Gaps, Problems and Recommendations

The last report (Jeffrey et. al., 2005) identified several areas where action could be taken to help conserve coral reefs. These included increased collaboration between agencies working on coral reef issues in the USVI, improving enforcement of existing regulations, expanding management capacity and increasing awareness of coral reef ecosystems among residents and visitors alike. Progress has been made in many of these areas, but additional efforts are warranted.

Several activities occurred within this reporting period to address these issues. Many workshops were held between federal, territorial and NGOs with the goals of identifying gaps in knowledge and effort, and strategizing to find ways to address them. Other workshops provided managers with tools to assess effectiveness of current management measures. However, much remains to be done. It is widely acknowledged that all agencies working for the conservation and management of coastal and marine areas in the USVI are limited by resources (staff, funding, technical capacity, etc.). In addition to increased collaboration and communication between agencies based in the territory, there is a need for their federal and international counterparts to do the same.

Lack of management and enforcement capacity continues to be a significant challenge for the USVI (Wusinich-Mendez and Curtis, 2007). Until coral reef ecosystem health is embraced as a community priority and reflected in policy and regulatory decisions, effective protection and management of these vital ecosystems will remain marginal. Enforcement agencies are chronically understaffed and territorial resource management offices experience significant staff turnover, particularly during administration changes. These staffing issues have in the past presented significant challenges to effective coral reef management, including: loss of institutional memory, a compromised thread of continuity, and abandonment of management processes which can stall program progress. Data on the direct and intrinsic economic value of USVI coral reef ecosystems would provide validation for the protection of these areas. Translation of this economic data into a format that can be distributed to policy makers and members of the public will increase the likelihood that coral reef health becomes a priority issue for the community. Formalized agency directives to increase collaborative efforts among resource management agencies would provide additional support for coral reef programs by leveraging of resources, minimizing duplicitous efforts, identifying gaps and minimizing competition for funds.

There continues to be a disconnect between scientists, resource managers and policy makers. Translation of scientific data on coral reef ecosystems into meaningful action such as revised management and planning policies (adaptive management), revised regulations and increased resources for initiatives remains a significant issue. A preliminary analysis of the percentage of conservation effort among agencies involved in coral reef issues in the USVI bears this out, and is presented in Figure 2.41 (Curtis, 2006). This analysis showed that while a large amount of effort (approximately 45%) is being expended on resource monitoring and public awareness activities, very little of that effort is translated into management activities like enforcement (3%), marine protected area establishment (6%) or habitat restoration (3%). New approaches and venues are needed to make coral reef science relevant and readily available to non-traditional audiences including policy makers, realtors, hoteliers, contractors and others.

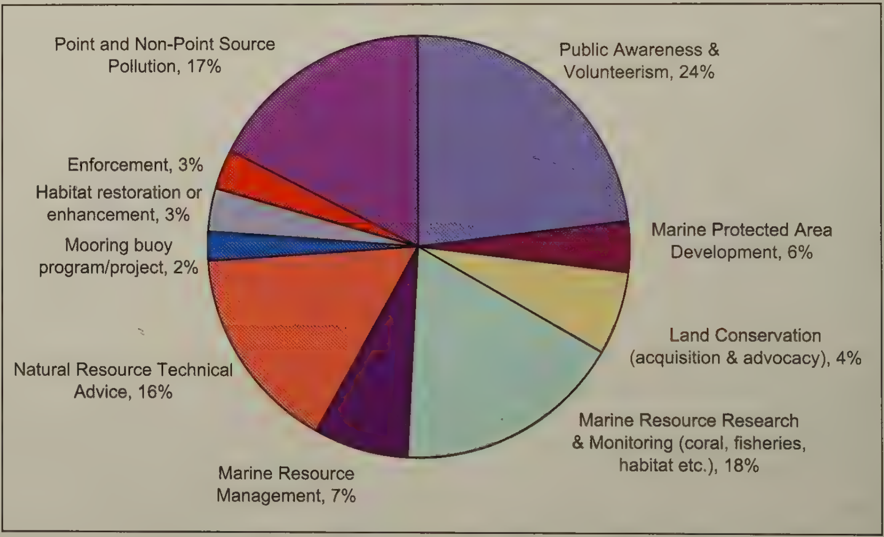


*Figure 2.41. Distribution of the percentage of conservation effort among 31 agencies or collaborating groups that contribute to coral reef conservation in the USVI. Percentages for each type of activity represent the number of agencies and/or collaborating groups engaged in that activity out of all agencies or collaborating groups working in coastal or marine resource issues in the USVI. Source: Curtis, 2006.*

The USVI has many of the necessary components for an effective regulatory framework to help restore coral reef ecosystem health, such as established MPAs, existing land use and resource management regulations, long-term data sets, and ongoing monitoring efforts. Initiatives such as zoning and implementation of other coastal and resource management regulations should be used in combination to develop a comprehensive strategy for the protection of coral reefs in the USVI. However, it is important to remember that successful implementation of protective policies is reliant upon perceived community value, technical capacity and political will.

## REFERENCES

Adey, W.H., W. Gladfelter, and R.D. Ogden. 1977. Field Guidebook to the reefs and reef communities of St. Croix, Virgin Islands. University of Miami. Miami, FL. 52 pp.

Beets, J. and A. Friedlander. 1992. Stock analysis and management strategies for red hind, *Epinephelus guttatus*, in the USVI. pp.66-79. In: Proceedings of the 42nd Gulf and Caribbean Fisheries Institute. Ochos Rios, Jamaica.

Bythell, J.C., Z. Hillis-Starr, and C.S. Rogers. 2000. Local variability but landscape stability in coral reef communities following repeated hurricane impacts. Mar. Ecol. Prog. Ser. 204: 93-100.

Catanzaro, D., C.S. Rogers, Z. HIllis-Starr, R.S. Nemeth, and M. Taylor. 2002. Status of Coral Reefs of the U.S. Virgin Islands. pp. 131-150. In: D.D. Turgeon, R.G. Asch, B.D. Causey, R.E. Dodge, W. Jaap, K. Banks, J. Delaney, B.D. Keller, R. Speiler, C.A. Mato, J.R. Garcia, E. Diaz, D. Catanzaro, C.S. Rogers, Z. Hillis-Starr, R.S. Nemeth, M. Taylor, G.P. Schmahl, M.W. Miller, D.A. Gulko, J.E. Maragos, A. Friedlander, C.L. Hunter, R.S. Brainard, R. Craig, R.H. Richmond, G. Davis, J. Starmer, M. Trianni, R. Houk, C.E. Birkeland, A. Edward, Y. Golbuu, J. Gutierrez, N. Idechong, G. Paulay, A. Tafileichig, and N.V. Velde (eds.). The State of Coral Reef Ecosystems of the United States and Pacific Freely Associated States: 2002. NOAA/NOS/NCCOS. Silver Spring, MD. 265 pp.

Clark, R.D., C.F.G. Jeffrey, K. Woody, Z. Hillis-Starr, and M.E. Monaco. In review. Spatial and temporal patterns of coral bleaching around Buck Island Reef National Monument, St. Croix, U.S. Virgin Islands. Bull. Mar. Sci.

Courtney, L.A., W.S. Fisher, S. Raimondo, L.M. Oliver, and W.P. Davis. 2007. Estimating three-dimensional colony surface area of field corals. J. Exp. Mar. Biol. Ecol. 351: 234-242.

Cox, C. and J.H. Hunt. 2005. Change in size and abundance of Caribbean spiny lobsters, *Panulirus argus*, in a marine reserve in the Florida Keys National Marine Sanctuary, USA. Mar. Ecol. Prog. Ser. 294: 227-239.

Cummings, N., R.J. Trumble, and R. Wakeford. 2007. Expansion of the SEAMAP-C Fishery-Independent Sampling Program Overview Document. SEDAR14-RD01. SEAMAP-Caribbean Committee. 13 pp. http://www.sefsc.noaa.gov/sedar/.

Curtis, S. 2006. Virgin Islands Coral Reef Needs and Solutions. 16th Meeting of the United States Coral Reef Task Force, Status of USVI Coral Reef Ecosystems Workshop. St. Thomas, USVI. 10 pp. http://epscor.uvi.edu/events/crtf_06_docs.html.

Donner, S., T. Knutson, and M. Oppenheimer. 2007. Model-based assessment of the role of human-induced climate change in the 2005 Caribbean coral bleaching event. In: Proceedings of the National Academy of Science 104(13): 5483-5488.

DPNR-DEP. 2004. The 2004 Integrated Water Quality Monitoring and Assessment Report for the United States Virgin Islands. Division of Environmental Protection, Department of Planning and Natural Resources, U.S. Virgin Islands. 193 pp. http://www.dpnr.gov.vi/dep/pubs/index.htm.

DPNR-DEP. 2006. The 2006 Integrated Water Quality Monitoring and Assessment Report for the United States Virgin Islands. Division of Environmental Protection, Department of Planning and Natural Resources, U.S. Virgin Islands. 131 pp. http://www.dpnr.gov.vi/dep/pubs/index.htm.

Eakin, C.M. 2007. Written Testimony of C. Mark Eakin, Ph.D. at Oversight Hearing on Wildlife and Oceans in a Changing Climate Before the Committee on Natural Resources Subcommittee on Fisheries, Wildlife, and Oceans. U.S. House of Representatives. http://www.legislative.noaa.gov/Testimony/Eakin041707.pdf.

Feary, D.A., G.R. Almany, G.P. Jones, and M. McCormick. 2007a. Coral degradation and the structure of tropical reef fish communities. Mar. Ecol. Prog. Ser. 333: 243-248.

Feary, D.A., G.R. Almany, G.P. Jones, and M. McCormick. 2007b. Habitat choice, recruitment and the response of coral reef fishers to coral degradation. Oecologia 153: 727-737.

Fishbase. 2000. Concepts, design and data sources. R. Froese and D. Pauly (eds.). ICLARM. Los Banos, Laguna, Phillipines.

Fisher, W.S. 2007. Stony Coral Rapid Bioassessment Protocol. Office of Research and Development, U.S. Environmental Protection Agency. Washington, DC. 72 pp. http://www.epa.gov/bioiweb1/coral/coral_biocriteria.html.

Fore, L.S., W.S. Fisher, and W.S. Davis. 2006a. Bioassessment Tools for Stony Corals: Field Testing of Monitoring Protocols in the US Virgin Islands (St. Croix). Office of Environmental Information, U.S. Environmental Protection Agency. Washington, DC. 51 pp. http://www.epa.gov/bioiweb1/coral/coral_biocriteria.html.

Fore, L.S., W.S. Fisher, and W.S. Davis. 2006b. Bioassessment Tools for Stony Corals: Monitoring Approaches and Proposed Sampling Plan for the U.S. Virgin Islands. Office of Environmental Information, U.S. Environmental Protection Agency. Washington, DC. 25 pp. http://www.epa.gov/bioiweb1/coral/coral_biocriteria.html.

Friedlander, A.M. 1997. Status of the queen conch populations around the northern USVI with management recommendations for the Virgin Islands National Park. Report to Biological Resources Division, U.S. Geological Survey. St. John, U.S. Virgin Islands. 40 pp.

Friedlander, A.M., R.S. Appeldoorn, and J. Beets. 1994. Spatial and temporal variations in stock abundance of queen conch, *Strombus gigas*, in the U.S. Virgin Islands. pp. 51-60. In: R.S. Appeldoorn and B. Rodriquez (eds.). Queen Conch Biology, Fisheries and Mariculture. Fundcion Cientifica Los Roques. Caracas, Venezuela. 359 pp.

Friedlander, A.F. and M.E. Monaco. 2007. Acoustic Tracking of Reef Fishes to Elucidate Habitat Utilization Patterns and Residence Times Inside and Outside Marine Protected Areas Around the Island of St. John, USVI. NOAA Technical Memorandum NOS NCCOS 63. Silver Spring, MD. 47 pp.

Garrison, V.H., E.A. Shinn, W.T. Foreman, D.W. Griffin, C.W. Holmes, C.A. Kellogg, M.S. Majewski, L.L. Richardson, K.B. Ritchie, and G.W. Smith. 2003. African and Asian dust: From desert soils to coral reefs. BioScience 53: 469-480.

Garrison, V.H., L.L. Richardson, and G.W. Smith. 2005. Disease on coral reefs - 2004 state of knowledge. pp. 152-165. In: R.C. Cipriano, I.S. Shchelkunov, and M. Faisal (eds.). Proceedings of the Second Bilateral Conference between Russia and the United States. Shephardstown, WV. 363 pp.

Gomez, R. 2000. SEAMAP-C USVI Summary Report: Fisheries Independent Sampling of the Shallow Water Reef Resources in the U.S. Virgin Islands, 1999-2000. Division of Fish and Wildlife, Department of Planning and Natural Resources, U.S. Virgin Islands.

Gordon, S. 2002. USVI Queen Conch Stock Assessment: Final Report to SEAMAP-C. Division of Fish and Wildlife, Department of Planning and Natural Resources, U.S. Virgin Islands. 64 pp. http://www.vifishandwildlife.com/Fisheries/FisheriesReports/

Graham, N.A., S.K. Wilson, S. Jennings, N.V. Polunin, J.P. Bijoux, and J. Robinson. 2006. Dynamic fragility of oceanic coral reef ecosystems. In: Proceedings of the National Academy of Science 103: 8425-8429.

Graham, N.A., S.K. Wilson, S. Jennings, N.V. Polunin, J. Robinson, J.P. Bijoux, and T.M. Daw. 2007. Lag effects in the impacts of mass coral bleaching on coral reef fish, fisheries, and ecosystems. Conserv. Biol. 21(5): 1291-1300.

Griffin, D.W., V.H. Garrison, C.A. Kellogg, and E.A. Shinn. 2001. African desert dust in the Caribbean atmosphere: Microbiology and public health. Aerobiologia 17: 203-213.

Griffin, D.W., C.A. Kellogg, V.H. Garrison, J.T. Lisle, T.C. Borden, and E.A. Shinn. 2003. Atmospheric microbiology in the northern Caribbean during African dust events. Aerobiologia 19: 143-157.

Griffin, E. and M. Paine. 2005. Draft Southeast Area Monitoring and Assessment Program (SEAMAP) Management Plan: 2006-2010. Caribbean SEAMAP Committee, South Atlantic Board. Atlantic States Marine Fisheries Commission and Technical Coordinating Committee. Gulf States Marine Fisheries Commission. 110 pp.

Hanlon, S. 2007. State of the Fisheries. In: The St. Croix Avis, Christiansted, USVI.

Hubbard, D.K., E.H. Gladfelter, and J.C. Bythell. 1993. Comparison of biological and geological perspectives of coral-reef community structure at Buck Island, U.S. Virgin Islands. pp. 201-207. In: R.N. Ginsburg (ed.). Proceedings of the Colloquium on Global aspects of coral reefs: health hazards, and history. Rosentiel School of Marine and Atmospheric Sciences, University of Miami. Miami, FL. 400 pp.

Jeffrey, C.F.G., U. Anlauf, J. Beets, S. Caseau, W. Coles, A. Friedlander, S. Herzlieb, Z. Hillis-Starr, M. Kendall, V. Mayor, J. Miller, R.S. Nemeth, C.S. Rogers, and W. Toller. 2005. The State of Coral Reef Ecosystems of the U.S. Virgin Islands. pp. 45-88. In: J.E. Waddell (ed.). The state of coral reef ecosystems of the United States and Pacific Freely Associated States: 2005. NOAA Technical Memorandum NOS NCCOS 11. Silver Spring, MD. 522 pp.

Jones, G.P. and C. Syms. 1998. Disturbance, habitat structure and the ecology of fishes on coral reef. Aust. J. Ecol. 23: 287-297.

Kadison, E., R.S. Nemeth, S. Herzlieb, and J. Blondeau. 2006. Temporal and spatial dynamics of *Lutjanus cyanopterus* (Pisces: Lutjanidae) and *L. jocu* spawning aggregations on a site in the United States Virgin Islands. Rev. Biol. Trop. 54: 69-78.

Kendall, M.S., C.R. Kruer, K.R. Buja, J.D. Christensen, M. Finkbeiner, R.A. Warner, and M.E. Monaco. 2001. Methods used to map the benthic habitats of Puerto Rico and the U.S. Virgin Islands. http://ccma.nos.noaa.gov/ecosystems/coralreef/usvi_pr_mapping.html.

Kojis, B. 2005. US Caribbean: NOAA Fisheries - State Marine Fisheries Directors' Biennial Meeting. St. Petersburg, FL.

Lundgren, I. and Z. HIllis-Starr. In revision. Variation in *Acropora palmata* bleaching across benthic zones at Buck Island Reef National Monument (St. Croix, USVI) during the 2005 bleaching event. Bull. Mar. Sci.

Mateo, I. and W. Tobias. 2001. Distribution of shallow water coral reef fishes on the northeast coast of St. Croix, USVI. Caribb. J. Sci. 37: 210-226.

Mateo, I. and W. Tobias. 2004. Survey of nearshore fish communities of tropical back reef lagoons on the southeastern coast of St. Croix. Caribb. J. Sci. 40: 327-342.

Mayor, P.A., C.S. Rogers, and Z.M. Hillis-Starr. 2006. Distribution and abundance of elkhorn coral, *Acropora palmata*, and prevalence of white-band disease at Buck Island National Monument, St. Croix, US Virgin Islands. Coral Reefs 25: 239-242.

McCreedy, C., J. Miller, C. Charles, and C.S. Rogers. 2006. Fact Sheet: Response to coral bleaching in U.S. Virgin Islands National Parks. 2006 Coral Reef Task Force Meeting. Washington, DC. http://www.coralreef.gov/announcements/NPS-USGS%20fact%20sheet.pdf.

Miller, J., C.S. Rogers, and R. Waara. 2003. Monitoring the disease, plague type II, on coral reefs in St. John, U.S. Virgin Islands. Rev. Biol. Trop. 51: 47-55.

Miller, J., R. Waara, A. Atkinson, B. Witcher, and M. Patterson. 2005. Protocol development to monitoring implementation: Lessons learned from the National Park Service's South Florida - Caribbean Inventory and Monitoring Network coral reef monitoring program. Presentation. 2006 Ocean Sciences Meeting. Honolulu, HI.

Miller, J., R. Waara, E. Muller, and C.S. Rogers. 2006. Coral bleaching and disease combine to cause extensive mortality on reefs in U.S. Virgin Islands. Coral Reefs 25(3): 418.

Monaco, M.E., J.D. Christensen, and S.O. Rohmann. 2001. Mapping and monitoring of U.S. coral reef ecosystems- the coupling of ecology, remote sensing and GIS technology. Earth System. Monitor. 12: 1-16.

Muller, E. 2007. Prevalence of disease on the coral *Acropora palmata* (Scleractinia) at Hawksnest Bay, St. John and colony recovery from white-pox lesions. Florida Institute of Technology. Melbourne, FL. 71 pp.

Muller, E.M., C.S. Rogers, A. Spitzack, R. van Woesik. 2008. Bleaching increases likelihood of disease on *Acropora palmata* (Lamarck) in Hawksnest Bay, St John, U.S. Virgin Islands. Coral Reefs 27(1): 191-195.

Nakamura, T. and R. van Woesik. 2001. Water flow rates and passive diffusion partially explain differential survival of corals during the 1998 bleaching event. Mar. Ecol. Prog. Ser. 212: 301-304.

Nemeth, R.S. 2005. Population characteristics of a recovering US Virgin Islands red hind spawning aggregation following protection. Mar. Ecol. Prog. Ser. 286: 81-97.

Nemeth, R.S., S. Herzlieb, M. Taylor, S. Harold, and W. Toller. 2003. Video monitoring assessment of coral reefs in St. Croix, United States Virgin Islands. Year two final report submitted to Department of Planning and Natural Resources. Division of Coastal Zone Management, Department of Planning and Natural Resources, U.S. Virgin Islands. 114 pp.

Nemeth, R.S., E. Kadison, S. Herzlieb, J. Blondeau, and E. Whiteman. 2004a. Status of yellowfin (*Mycteroperca venenosa*) and Nassau (*Epinephelus striatus*) grouper spawning aggregations in the US Virgin Islands with notes on other species. pp. 543-558. In: Proceedings of the 56th Gulf and Caribbean Fisheries Conference. Tortola, British Virgin Islands. 851 pp.

Nemeth, R.S., S. Herzlieb, E.S. Kadison, M.G. Taylor, J.P. Rothenberger, and S. Harold. 2004b. Coral reef monitoring in St. Croix and St. Thomas, United States Virgin Islands. Year Three Final Report Submitted to Department of Planning and Natural Resources. Division of Coastal Zone Management, Department of Planning and Natural Resources, U.S. Virgin Islands. 120 pp.

Nemeth, R.S., S. Herzlieb, E. Kadison, M. Taylor, and W. Toller. 2004c. Coral reef monitoring in St. Croix and St. Thomas, United States Virgin Islands. Year four final report prepared for Department of Planning and Natural Resources. Division of Coastal Zone Management, Department of Planning and Natural Resources, U.S. Virgin Islands. 120 pp.

Nemeth, R.S., T.B. Smith, M. Taylor, S. Herzlieb, E. Kadison, J. Blondeau, L. Carr, and L. Allen-Requa. 2005. Coral Reef Monitoring in St. Croix and St. Thomas, United States Virgin Islands. Year Five Final Report Submitted to Department of Planning and Natural Resources. Division of Coastal Zone Management, Department of Planning and Natural Resources, U.S. Virgin Islands. 61 pp.

Nemeth, R.S., S. Herzlieb, and J. Blondeau. 2006a. Comparison of two seasonal closures for protecting red hind spawning aggregations in the US Virgin Islands. pp. 1306-1313. In: Y. Suzuki, T. Nakamori, M. Hidaka, H. Kayanne, B.E. Casareto, K. Nadaoka, H. Yamano, and M. Tsuchiya (eds.). Proceedings of the 10th International Coral Reef Symposium. Okinawa, Japan. 1950 pp.

Nemeth, R.S., E. Kadison, S. Herzlieb, J. Blondeau, and E. Whiteman. 2006b. Status of a yellowfin grouper (*Mycteroperca venenosa*) spawning aggregation in the US Virgin Islands with notes on other species. pp. 543-558. In: Proceedings of the 57th Gulf and Caribbean Fisheries Institute. St. Petersburg, FL. 1048 pp.

Nemeth, R.S., S. Herzlieb, J. Blondeau, and E. Kadison. 2007. Spatial and temporal patterns of movement and migration at spawning aggregations of red hind, *Epinephelus guttatus*, in the U.S. Virgin Islands. Environ. Biol. Fish. 78: 365-381.

Olsen, D.A. and J.A. LaPlace. 1978. A study of Virgin Islands grouper fishery based on a breeding aggregation. pp. 130-144. In: Proceedings of the 31st Gulf and Caribbean Fisheries Institute. Cancun, Mexico.

Pagan F.E., A.R. Marshak, I. Ruiz, and E.O. Serrano. 2004. Caribbean SEAMAP Program Reef Fish: USVI Summary Overview. University of Puerto Rico Sea Grant College Program/NMFS SEAMAP-C. www.sefsc.noaa.gov/sedar/download/Caribbean-SEAMAPReef%20Fish.ppt?id=DOCUMENT.

Pomeroy, R.S., J.E. Parks, and L.M. Watson. 2004. How is your MPA doing? A Guidebook of Natural and Social Indicators for Evaluating Marine Protected Area Management Effectiveness. IUCN. Gland Switzerland and Cambridge, UK. 234 pp.

Randall, J.E. 1967. Food habits of reef fishes of the West Indies. Stud. Trop. Oceanogr. 5: 665-847.

Randall, J.E. 1996. Caribbean Reef Fishes. T.F.H. Publications, Inc. Neptune City, NJ. 368 pp.

Ritchie, K.B. 2006. Regulation of marine microbes by coral mucus and mucus associated bacteria. Mar. Ecol. Prog. Ser. 322: 1-14.

Rogers, C.S. 2003. Will the major reef-building species *Acropora palmata* (elkhorn coral) recover in the US and British Virgin Islands? pp. 439-452. In: Proceedings of the 56th Gulf and Caribbean Fisheries Institute. Tortola, British Virgin Islands. 851 pp.

Rogers, C.S. 2006. Threats to Coral Reefs in the US Virgin Islands. In: 16th Meeting of the United States Coral Reef Task Force, Status of USVI Coral Reefs Workshop. St. Thomas, U.S.Virgin Islands. 30 pp. http://epscor.uvi.edu/events/crtf_06_docs.html.

Rogers, C.S., V.H. Garrison, and R. Grober-Dunsmore. 1997. A fishy story about hurricanes and herbivory: seven years of research on a reef in St. John, U.S. Virgin Islands. pp. 555-560. In: H.A. Lessios and I.G. Macintyre (eds.). Proceedings of the 8th International Coral Reef Symposium, Vol. 1. Panama City, Panama. 1040 pp.

Rogers, C.S. and J. Beets. 2001. Degradation of marine ecosystems and decline of fishery resources in marine protected areas in the U.S. Virgin Islands. Environ. Conserv. 28: 312-322.

Rogers, C.S. and J. Miller. 2001. Coral bleaching, hurricane damage, and benthic cover on coral reefs in St. John, U.S. Virgin Islands: a comparison of surveys with the chain transect method and videography. Bull. Mar. Sci. 69: 459-470.

Rogers, C.S., E. Muller, B. Devine, and P. Nieves. 2005. Mapping the spatial distribution of diseases affecting elkhorn coral within Virgin Islands National Park: a closer look at an "endangered" reef-building species. Report to Disney Wildlife Conservation Fund. 6 pp + figures.

Rogers, C.S., E. Muller, A. Spitzack, B. Devine, P. Nieves, and E. Gladfelter. 2006. A closer look at elkhorn coral (*Acropora palmata*) on two reefs within Virgin Islands National Park: the role of disease, physical breakage, predation, and competition. Report to Disney Wildlife Conservation Fund. 8 pp + figures.

Rogers, C.S., J. Miller, E. Muller, P. Edmunds, R.S. Nemeth, J. Beets, A. Friedlander, T.B. Smith, R. Boulon, C.F.G. Jeffrey, C. Menza, C. Caldow, N. Idrisi, B. Kojis, M. Monaco, A. Spitzack, E. Gladfelter, J. Ogden, Z. Hillis-Starr, I. Lundgren, W.B. Schill, I. Kuffner, L.L. Richardson, B. Devine, and J. Voss. In press. Ecology of Coral Reefs in the U.S. Virgin Islands. pp. 303-374. In: B. Riegl and R.E. Dodge (eds.). Coral Reefs of the USA. Coral Reefs of the World, Volume 1. Springer. 806 pp.

Rohmann, S., J. Hayes, R. Newhall, M. Monaco, and R. Grigg. 2005. The area of potential shallow-water tropical and subtropical coral ecosystems in the United States. Coral Reefs 24: 370-383.

Rothenberger, J.P. 2006. The Status of USVI Coral Reef Ecosystems Workshop Update. In: 16th U.S. Coral Reef Task Force Meeting. St. Thomas, USVI. http://www.coralreef.gov/taskforce/meetings/meet9.html.

Shinn, E.A., G.W. Smith, J.M. Prospero, P. Betzer, M.L. Hayes, V.H. Garrison, and R.T. Barber. 2000. African dust and the demise of Caribbean coral reefs. Geophys. Res. Lett. 27: 3029-3032.

Smith, G.W., L.D. Ives, I.A. Nagelkerken, and K.B. Ritchie. 1996. Caribbean sea-fan mortalities. Nature 383: 487.

Smith, T., R.S. Nemeth, J. Blondeau, J. Calnan, E. Kadison, and S. Herzlieb. In preparation. Assessing Coral Reef Health Across On-shore to Offshore Stress Gradients in the USVI. Mar. Poll. Bull.

Sokal, R.R. and F.J. Rohlf. 1995. Biometry: The Principles and Practice of Statistics In Biological Research (3rd ed.). W.H. Freeman and Company. Stony Brook, NY. 850 pp.

Steneck, R.S. 1988. Herbivory on coral reefs: a synthesis. pp. 37-49. In: Proceedings of the 6th International Coral Reef Symposium, Vol. 1. Townsville, Australia. 285 pp.

Stoner, A.W. and M. Ray. 1996. Queen conch, *Strombus gigas*, in fished and unfished locations of The Bahamas: effects of a marine fishery reserve on adults, juveniles and larval production. Fish. Bull. 94: 551-565.

Tobias, W. Division of Fish and Wildlife, Department of Planning and Natural Resources, U.S. Virgin Islands. Frederiksted, St. Croix, U.S. Virgin Islands. Personal communication.

Tobias, W., W. Toller, W. Ventura, and H. Rivera. 2002. SEAMAP-C USVI Summary Report: St. Croix Fisheries Independent Trap and Line Survey, 2000-2002. Division of Fish and Wildlife, Department of Planning and Natural Resources, U.S. Virgin Islands. 27 pp. http://www.vifishandwildlife.com/Fisheries/FisheriesReports/.

Tobias, W. 2004. Netfishing overview - St. Croix, U.S. Virgin Islands. Management implications for restrictions on the use of gill and trammel nets. Summary Report prepared for the Commissioner of DPNR. Division of Fish and Wildlife, Department of Planning and Natural Resources, U.S. Virgin Islands. 21 pp. http://www.vifishandwildlife.com/Fisheries/FisheriesReports/2004/.

Tobias, W. 2005. Assessment of Conch Densities in Backreef Embayments on the northeast and southeast coast of St. Croix, U.S. Virgin Islands. Report to Southeast Area Monitoring and Assessment Program-Caribbean (SEAMAP-C). Division of Fish and Wildlife, Department of Planning and Natural Resources, U.S. Virgin Islands. 34 pp. http://www.vifishandwildlife.com/Fisheries/FisheriesReports/2005/ConchDensities.pdf.

Toller, W. 2002. Quantitative estimates of species composition and abundance of fishes, and fish species/habitat associations in St. Croix, U.S. Virgin Islands. Final Report, F-7-17. Division of Fish and Wildlife, Department of Planning and Natural Resources, U.S. Virgin Islands. 44 pp. http://www.vifishandwildlife.com/Fisheries/FisheriesReports/2002/.

Toller, W. 2006. F7 Recreational Fisheries Habitat Assessment Project: Final Completion Report, Part 2. An Investigation of Anchor Damage to the Frederiksted Reef System: Impacts to Substrate, Benthic Communities and Reef Fish Assemblages. Division of Fish and Wildlife, Department of Planning and Natural Resources, U.S. Virgin Islands. 58 pp. http://www.vifishandwildlife.com/Fisheries/FisheriesReports/2006/2006Reports.htm.

Toller, W. and W. Tobias. 2005. Management Implications for Restrictions on the use of Gill and Trammel Nets in St. Croix, U.S. Virgin Islands. In: Proceedings of the 58th Gulf and Caribbean Fisheries Institute. San Andres, Colombia. 518 pp. http://www.vifishandwildlife.com/Fisheries/FisheriesReports/2004/.

Trumble, R.J., N. Cummings, W. Tobias, W. Toller, W. Ventura, and H. Rivera. 2006. A pilot program to assess methods of collecting bycatch, discard, and biological data in the commercial fisheries of the US Caribbean. Final Report. Southeast Regional Fisheries Office, NOAA National Marine Fisheries Service. 79 pp. http://www.vifishandwildlife.com/Fisheries/FisheriesReports/2006/

Vollmer, S.V. and S.R. Palumbi. 2007. Restricted Gene Flow in the Caribbean staghorn coral *Acropora cervicornis*: Implications for the Recovery of Endangered Reefs. J. Hered. 98: 40-50.

Weir-Brush, J.R., V.H. Garrison, G.W. Smith, and E.A. Shinn. 2004. The relationship between Gorgonian coral (Cnidaria: Gorgonacea) diseases and African dust storms. Aerobiologia 20: 119-126.

Whiteman, E.A. 2005. SEAMAP-C USVI St. Croix & St. Thomas/St. John fisheries independent trap and line surveys, 1992-2002. Summary report: data analysis and conclusions. UPR Seagrant College Program/NMFS SEAMAP-C. 50 pp. http://www.vifishandwildlife.com/Fisheries/FisheriesReports/2005/.

Whiteman, E.A., C.A. Jennings, and R.S. Nemeth. 2003. Sex structure and potential female fecundity in an *Epinephelus guttatus* spawning aggregation; applying ultrasound imaging. J. Fish Bio. 66: 983-995.

Williams, D.E., M.W. Miller, and K.L. Kramer. 2006. Demographic Monitoring Protocols for Threatened Caribbean *Acropora* spp. Corals. NOAA Technical Memorandum NMFS SEFSC 543. Miami, FL. 91 pp.

Wilson, S.K., N.A.J. Graham, M.S. Pratchett, G.P. Jones, and N.V.C. Polunin. 2006. Multiple disturbances and the global degradation of coral reefs: are reef fishes at risk or resilient? Global Change Biol. 12: 2220-2234.

Wood, R.S. and D.A. Olsen. 1983. Application of biological knowledge to the management of the Virgin Islands conch fishery. pp.112-121. In: Proceedings of the 35th Gulf and Caribbean Fisheries Institute. Nassau, Bahamas.

Wurster, C.F. 1968. DDT reduces photosynthesis by marine phytoplankton. Science 159(3822): 1474-1475.

Wusinich-Mendez, D. and S. Curtis. 2007. USVI Coral Reef MPA Summary. pp 117-129. In: D. Wusinich-Mendez and C. Trappe (eds.). Report on the Status of Marine Protected Areas in Coral Reef Ecosystems of the United States Volume 1: Marine Protected Areas Managed by U.S. States, Territories and Commonwealths: 2007. NOAA Technical Memorandum CRCP 2. Silver Spring, MD. 129 pp.

# The State of Coral Reef Ecosystems of Puerto Rico

Jorge García-Sais[1], Richard Appeldoorn[1], Tim Battista[2], Laurie Bauer[2], Andy Bruckner[3], Chris Caldow[2], Lisamarie Carrubba[4], Jorge Corredor[1], Ernesto Diaz[5], Craig Lilyestrom[6], Graciela García-Moliner[7], Edwin Hernández-Delgado[8], Charles Menza[2], Julio Morell[1], Anthony Pait[9], Jorge Sabater[10], Ernesto Weil[1], Ernest Williams[1] and Stephanie Williams[1]

## INTRODUCTION AND SETTING

The Commonwealth of Puerto Rico is comprised of a number of islands in the northern Caribbean, including the island of Puerto Rico and offshore islands such as Culebra, Vieques, Monito, and Desecheo (Figure 3.1). The following information adds to the comprehensive overview of Puertorrican reefs provided in the previous edition of this report (García-Sais et al., 2005). The coral reef ecosystem in Puerto Rico is a complex mosaic of interrelated habitats, including mangrove forests, seagrass beds and coral reefs, as well as other coral communities. Mangrove forests can be found on coral cays and fringing the shoreline along the coast. In areas along the coast where development is occurring, mangrove forests and other wetlands continue to be impacted by cutting, filling and other disturbances. The desire for water access and increases in boating also impact both mangroves and seagrass beds directly through construction and indirectly through changes in water quality associated with accidental spills of petroleum products, accidental groundings and propeller damage, and increases in marine debris. Impacts to these important habitats also lead to effects in coral reefs due to the loss of juvenile habitat for reef species such as spiny lobster, snappers, and groupers. Frias-Torres (2006) demonstrated that, for mangrove-dependent juveniles of goliath grouper in the Florida Keys, spatially complex fringing red mangrove habitat was essential to the growth of this species and the later presence of adults in coral reefs and colonized hardbottom.

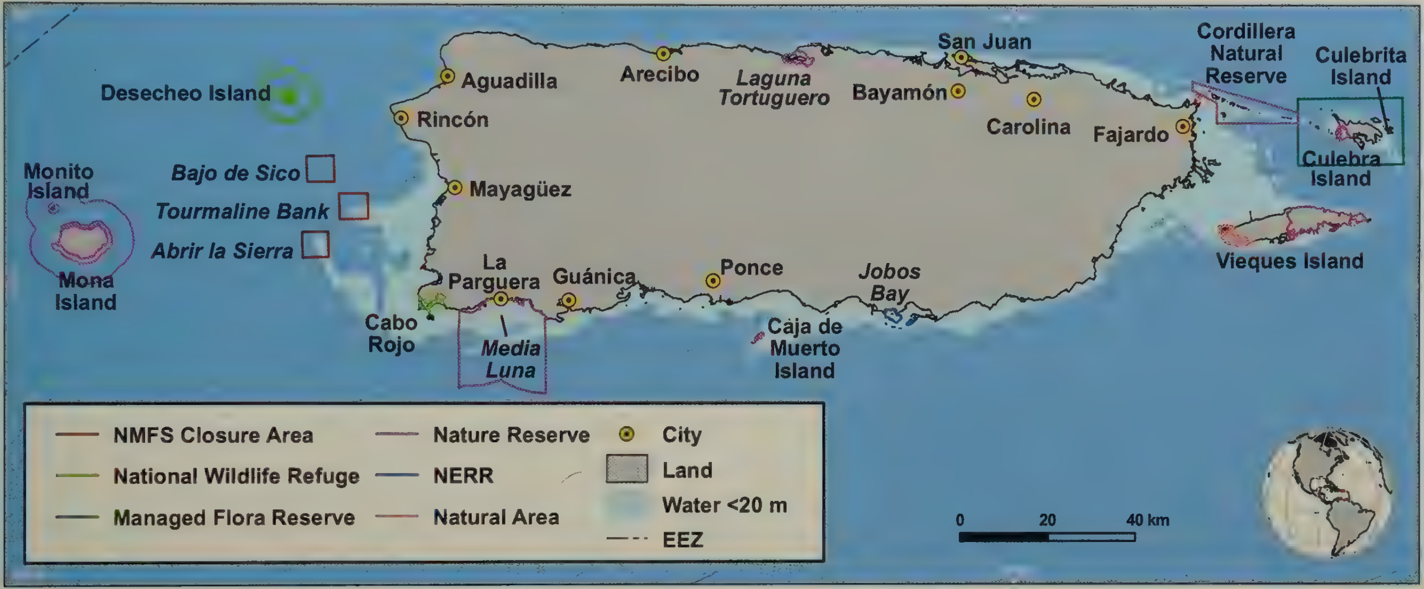

Desecheo Island
Monito Island
Mona Island
Bajo de Sico
Tourmaline Bank
Abrir la Sierra
Aguadilla
Rincón
Mayagüez
Cabo Rojo
La Parguera
Media Luna
Guánica
Arecibo
Laguna Tortuguero
Ponce
Caja de Muerto Island
Jobos Bay
Bayamón
San Juan
Carolina
Fajardo
Cordillera Natural Reserve
Culebrita Island
Culebra Island
Vieques Island
NMFS Closure Area
National Wildlife Refuge
Managed Flora Reserve
Nature Reserve
NERR
Natural Area
City
Land
Water <20 m
EEZ
0
20
40 km

Figure 3.1. A map of Puerto Rico showing locations mentioned in this chapter. Map: K. Buja.

Seagrass beds provide habitat for various life stages of numerous highly mobile species that also utilize red mangrove roots and coral reefs during various parts of their life cycle. Aguilar-Perera (2004) evidenced the importance of seagrasses in La Parguera Natural Reserve as habitat for juvenile populations of species of commercial importance such as grunts and snappers. Similarly, the underestimation of the extent of seagrass habitats often results in lesser protection to these important communities. The proper definition of the extent of seagrass habitat is confounded by various factors, including temporal changes that may be a function of season, changes in light penetration, wave energy, and direct human disturbances such as dredging, propeller wash and scars, and anchoring (Fonseca et al., 1998). The Caribbean Fishery Management Council or CFMC (2004) states that the degradation and loss of patchy seagrass habitat, essential for the settlement and development of juvenile conch, may be one of the reasons the species is considered overfished, as a reduction in juvenile habitat results in a loss of productivity. Overall, the proper definition of the extent of seagrass habitats should recognize the variability of seagrass coverage, the reproductive needs of the grasses (vegetative and sexual), and the historical record related to seagrass presence in an area. Estimates of seagrass habitat coverage based on one-time observations will probably result in underestimates.

---

1. University of Puerto Rico, Mayaguez
2. NOAA Ocean Service, Center for Costal Monitoring and Assessment, Biogeography Branch
3. NOAA Fisheries, Office of Habitat Conservation
4. NOAA Fisheries, SERO Protected Resources Division
5. Puerto Rico Costal Zone Management Program
6. Puerto Rico Department of Natural and Environmental Resources
7. Caribbean Fisheries Management Council
8. University of Puerto Rico, Rio Piedras
9. NOAA Ocean Service, Center for Costal Monitoring and Assessment, Coastal Oceanographic Assessment Status and Trends Branch
10. Reef Research, Inc

In addition to human impacts to benthic habitats that form the coral reef ecosystem in Puerto Rico, declines in the health of important reef-building corals have become a concern of NOAA in the U.S. Caribbean and Florida. In 2004, NOAA Fisheries received a petition from the Center for Biological Diversity to protect elkhorn (*Acropora palmata*), staghorn (*A. cervicornis*) and fused staghorn (*A. prolifera*) corals under the Endangered Species Act (ESA) of 1973. NOAA Fisheries found the petition had merit and convened a Biological Review Team (BRT) to review the status of these species. The BRT found that elkhorn and staghorn corals used to be the most abundant and most important species on many Caribbean coral reefs in terms of reef formation and the provision of habitat for other reef organisms (Acropora Biological Review Team, 2005). The BRT determined that, due to the decreased abundance of elkhorn and staghorn corals, it is likely that the ecosystem functions related to growth of coral reefs and provision of habitat have been greatly compromised (Acropora Biological Review Team, 2005). The BRT determined that disease, temperature-induced coral bleaching, and physical damage from hurricanes were the greatest threats to these corals followed by anthropogenic physical damage such as groundings, anchoring, and divers/snorkelers. Based on the results of the status review, NOAA Fisheries decided to list elkhorn and staghorn corals as threatened throughout their known range. This designation became final in May 2006. In addition, because the species were listed as threatened, NOAA Fisheries proposed take prohibitions under Section 4(d) of the ESA. Once final, these prohibitions will protect these corals from damage related to collection, construction, groundings, and other anthropogenic activities while still allowing scientific investigation and education to promote their recovery. NOAA Fisheries is also proposing the designation of critical habitat for these species that would protect hardbottom habitat where these corals were present historically or are currently found.

In addition to the reef types described in García-Sais et al. (2005a), deep hermatypic coral formations off the south coast of Vieques, Isla Desecheo and Bajo de Sico in Mona Passage have recently been described by García-Sais et al. (2004, 2005b, 2005c, 2006) as part of the Puerto Rico National Coral Reef Monitoring Program of the Department of Natural and Environmental Resources (DNER), and the Essential Fish Habitat Program of the CFMC, both programs sponsored by NOAA. Quantitative assessments of reef substrate cover by sessile-benthic, motile megabenthic and fish communities were produced by García-Sais et al. (2004, 2005b, 2005c, 2006) for these deep hermatypic reef systems (mesophotic reefs). The benthic communities associated with the upper slope habitat off La Parguera were described by Singh et al. (2004) from photographic records provided by the SeaBED Autonomous Underwater Vehicle. information on additional mesophotic reef types is provided below.

*Deep Hermatytpic Coral Formations (Mesophotic reefs)*

Deep hermatypic coral formations recently described in Puerto Rico include the "Deep Terrace", "Drop-off Wall" and "Rhodolith" reefs, which contain nodules of unattached, branching, coralline algae. "Deep Terrace" reefs have been found at depths between 30-90 meters growing over flat or gently sloping terraces in very clear water. The dominant coral species is a flattened plate morphotype of *Montastraea annularis* complex; lettuce corals (*Agaricia lamarki*, *A. grahame*) and *Porites astreoides* are also common. García-Sais et al. (2004) described one of these reefs, locally known as Black Jack, off the south coast of Isla de Vieques (Figure 3.2). The reef is similar to those reported by Nemeth et al. (2004), and Armstrong et al. (2006) within the Marine Conservation District off the south coast of St. Thomas, U.S. Virgin Islands (USVI), a known spawning aggregation site for red hind (*Epinephelus guttatus*; Nemeth et al., 2005). Similar reef formations may be present off the east and south coasts of Vieques, north-east coast of Culebra, and on deep terraces of the outer insular shelf of the USVI. Some of these reefs are important spawning aggregation sites for groupers. El Seco, an undescribed deep terrace reef formation located off the east coast of Vieques is a known spawning aggregation site for tiger grouper (*Mycteroperca tigris*; Sadovy et al., 1994).

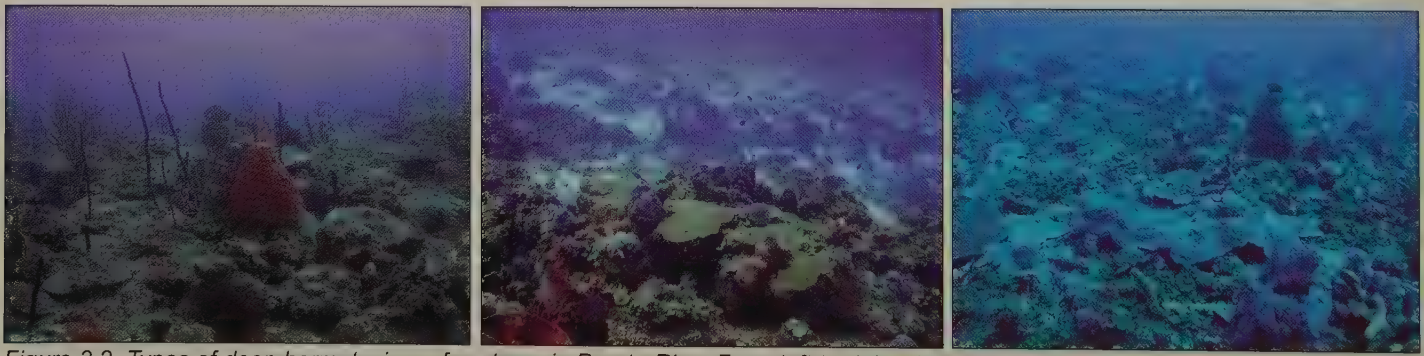


*Figure 3.2. Types of deep hermatypic reef systems in Puerto Rico. From left to right: deep terrace reef type; Black Jack Reef, Isla de Vieques, Puerto Rico (34 m; left); Drop-off wall reef type, and southeast Wall Reef, Isla Desecheo, Puerto Rico (40 m; center); and Rhodolith reef type. Agelas Reef, Isla Desecheo, Puerto Rico (50 m; right). Source: García-Sais et al., 2005.*

A total of 25 species of scleractinian corals, two antipatharians and one hydrocoral were identified during the snapshot survey of Black Jack Reef by García-Sais et al. (2004). Live coral cover averaged 28.8% (range 25.0-40.4%) within video-transect areas. The *Montastraea annularis* complex was the dominant coral species in terms of substrate cover (mean: 21.9%), representing 76% of the total live coral cover at depths between 36-40 m., and generally exhibited laminar or flattened growth with closely spaced colonies of moderate size and low relief. Corals grow mostly from a pedestal of unknown origin, creating protective habitat underneath the coral. The laminar growth pattern appears to be an adaptation for optimum light utilization. Other coral species that presented substrate cover above 1% and that were present in at least four out of five transects surveyed include *Porites astreoides*, *Agaricia grahamae* and *M. cavernosa*. One large colony of the bushy black coral (*Antipathes caribbeana*) was present at the deep terrace of Black Jack Reef. Turf algae was the dominant biological assemblage in terms of reef substrate cover with 57.4 %. Fleshy (*Lobophora variegata*) and calcareous algae (*Halimeda* sp.) were also present within transect areas. The combined mean reef substrate cover by benthic algae within transect areas surveyed was 64.2% (García-Sais et al., 2004).

A total of 54 reef fishes were identified from Black Jack Reef, 33 of which were present within three (3 x 10 m) belt-transects surveyed between 10:00–12:00 AM (García-Sais et al., 2004). The mean abundance of fishes was 549.3 individuals/30 m$^2$ and the mean number of species per transect was 16. An assemblage of three species represented 95% of the total fish abundance within belt-transects. The numerically dominant species was the masked goby (*Coryphopterus personatus*) with a mean abundance of 390 individuals/30 m$^2$. This is the highest density ever reported for a demersal fish within a belt-transect from a reef surveyed in Puerto Rico. Following in abundance were the Creole wrasse (*Clepticus parrae*) with 93.0 individuals/30 m$^2$ and the blue chromis (*Chromis cyanea*) with 36.7 individuals/30 m$^2$.

An extensive Deep Terrace reef formation associated with the submerged seamount at Bajo de Sico (Mona Passage) has been recently described (García-Sais et al., unpub. data). The reef extends across the entire northwest section of the seamount at depths between 45 and 90 meters over a relatively flat, gently sloping, hard bottom terrace. Biological characterization and benthic habitat mapping efforts of this reef system are ongoing at present as part of a project sponsored by the CFMC and NOAA, with the support of NOAA's Center for Coastal Monitoring and Assessment Biogeography Branch (CCMA-BB).

### *Drop-off Wall Reefs*

Deep hermatypic reefs have developed on drop-off walls at the upper slope of oceanic islands, such as Isla Desecheo (García-Sais et al., 2005b), and on the reef top and upper slope of the seamount at Bajo de Sico in Mona Passage (García-Sais et al., in review). The Southwest Wall reef of Isla Desecheo is found at depths between 30-40 m and is dominated by benthic macroalgae (mostly *Lobophora variegata*), sand, sponges and massive scleractinian corals (García-Sais et al., 2005b). Sponges are highly prominent (mean surface cover: 17.3%), growing mostly as large erect and branching forms that provide substantial topographic relief and protective habitat for fishes and invertebrates. In many instances, sponges grow attached to stony corals forming sponge-coral bioherms of considerable size. One of the most common associations consists of brown tube (*Agelas conifera*, *A. sceptrum*) and row pore sponges (*Aplysina* spp.) with star corals (*Montastraea cavernosa*, *M. annularis*). A total of 25 scleractinian corals, three hydrocorals and two antipatharian (black coral) species were identified from the Southwest Wall Reef at Isla Desecheo. Great star corals (*M. cavernosa*, *M. annularis* complex) were the dominant species of scleractinian corals at the site (García-Sais et al., 2005b).

A total of 70 fish species were identified from depths below 30 m at southwest Wall reef (García-Sais et al., 2005b). The numerically dominant ichthyofauna within belt-transects surveyed was comprised by zooplanktivorous taxa, suggesting that planktonic food webs are most relevant on deep hermatypic reefs. Drop-off wall reefs studied at Isla Desecheo are the natural habitats of many exploited commercially important food fishes, such as large groupers (*Epinephelus striatus*, *E. guttatus*, *Mycteroperca venenosa*) and snappers (*Lutjanus spp.*), and target species of the aquarium trade (*Chromis cyanea*, *Gramma loreto*, *Centropyge argi*, *Chaetodon* spp., *Opistognathus* spp.). Densities of adult red hind (*E. guttatus*) from 40 m at the southwest Wall are the highest reported for Puerto Rico (García-Sais et al., 2005b).

### *Rhodolith Reefs*

Rhodolith reefs have developed along gently sloping terraces below depths of 40 m at Isla Desecheo and Bajo de Sico. Agelas Reef is a crustose algal rhodolith formation colonized by encrusting brown algae (*Lobophora variegata*), large erect and branching sponges (*Agelas* spp., *Aplysina* spp.) and lettuce corals (*Agaricia* spp) found at depths of 40-70 m in Isla Desecheo (García-Sais et al., 2005b; Figure 3.2). The sessile-benthic biota, including corals, grows attached to a vast deposit of rhodolite nodules that are loosely anchored to the bottom. Reef substrate cover by live biota is over 95%. Agelas Reef has very low topographic relief and massive corals do not contribute significantly to its rugosity. A total of 18 species of scleractinian corals, two hydrozoans (*Millepora alcicornis* and *Stylaster roseus*) and the antipatharian black wire coral (*Stichopathes lutkeni*) have been reported from Agelas Reef (García-Sais et al., 2005b). The combined mean substrate cover by the nine species of scleractinian corals present within video-transects at Agelas Reef was 13.1% (range: 7.4-36.4%). Irregular sheets or laminar growth by lettuce corals prevailed at depths between 45 and 53 meters, with a combined reef substrate cover of 8.9%, representing 70% of the total cover by scleractinian corals. Lamark's sheet coral (*Agaricia lamarki*) and Graham's sheet coral (*A. grahamae*) were the main coral species present within transects surveyed (García-Sais et al., 2005b).

# ENVIRONMENTAL AND ANTHROPOGENIC STRESSORS

## Climate Change and Coral Bleaching

The 2005 coral bleaching event and post-bleaching coral mass mortality during 2006 had a dramatic impact on Puerto Rican coral habitats. Major coral bleaching resulted from record-breaking warm sea surface temperatures (SSTs; up to 31.8°C at 30 m depths, and up to 33.1°C at reef crests), and a maximum of 14.3 accumulated degree heating weeks or DHW (Hernández-Delgado, unpub. data). A total of 82 cnidarian species were impacted by bleaching in Puerto Rico during 2005, including 52 scleractinians, 13 octocorals, four hydrocorals, four zoanthideans, four actiniarians, three corallimorpharians and two scyphozoans (Hernández-Delgado et al.,unpub. data; García-Sais et al., 2006).

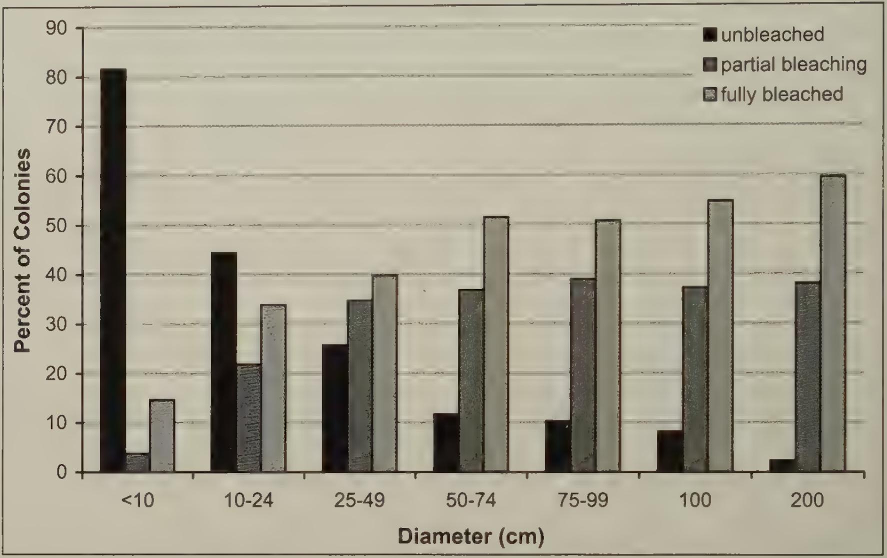


Figure 3.3. Relationship between colony size and bleaching severity, recorded as unbleached, partial bleaching and fully bleached (all locations and species are pooled). Source: Hernández-Delgado, unpub. data.

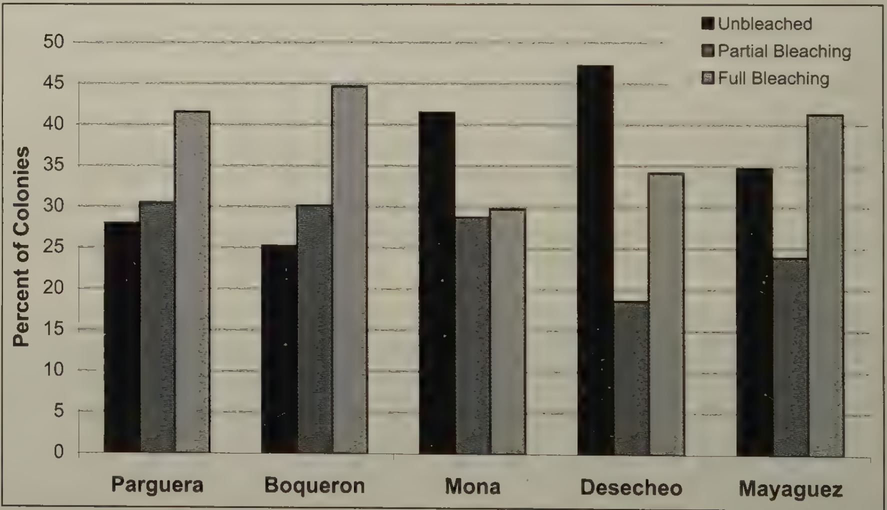


Figure 3.4. Site specific variation in bleaching observed on 70 belt transects (1 x 30 m) off southwest Puerto Rico, Mona Island and Desecheo Island (28 reefs <30 m depth). Colonies (all species pooled, n=4,030 corals) were identified as unbleached (normal pigmentation), partially bleached (pale or mottled coloration) or fully bleached (>80% of colony surface). Source: Hernández-Delgado, unpub. data.

Stratified random belt transects (back reef and fore reef locations from 1-30 m depth) were conducted off La Parguera, Mayaguez, Boqueron, Rincon and the offshore islands of Desecheo and Mona Island in December, 2005 and August 2006 to quantify the extent of bleaching and patterns of recovery. Of over 4,000 corals examined in all sites during December (70 belt transects in 28 locations), 65% of the corals exhibited signs of bleaching ranging from fully bleached (white) to partially bleaching (pale yellow or mottled appearance), represented by 73% of the total living coral cover, while 35% of the colonies did not appear to have been affected by this event. Differences in bleaching severity and extent of mortality were observed between species, colony size, locations and depths (Figures 3.3, 3.4, and 3.5). Overall, colonies in Parguera exhibited higher rates of bleaching (all species pooled) and higher percent of recent tissue loss (5.4%) when compared to sites off the west coast (1.4-2.8%), while more normal, unbleached corals were observed on reefs off Mona Island (42%) and Desecheo Island (47%). The most severe bleaching (all sites pooled) was observed among *Montastraea annularis* complex (94%), *Helioseris cucullata* (94%), *Colpophyllia natans* (83%), *Siderastrea siderea* (65%), *Millepora* spp. (63%), *Mycetophyllia* spp.(62%), *Diploria* spp.(54%), *Agaricia* spp. (48%) and *M. cavernosa* (46%). In contrast, *Eusmilia fastigiata* (22%), *Meandrina meandrites* (26%), and *Porites* spp. (36%) appeared to be less susceptible to bleaching. Several less common species, such as *Dichocoenia stokesii, Dendrogyra cylindricus, Isophyllia sinuosa, Mussa angulosa, Scolymia lacera* and *Manacina areolata* were fully bleached on reefs around La Parguera, and less frequently bleached in other locations. *Millepora alcicornis* exhibited complete bleaching at all sites, and most colonies (>65%) had died by December 2005. Complete bleaching and extensive partial mortality of *Acropora palmata* colonies was documented off Parguera; this species was partially bleached off Mayaguez and no bleaching was observed within *A. palmata* thickets off Rincon, Boqueron and Mona Island. Differences in the extent of bleaching were largely size dependent, with the smallest corals exhibiting both the highest resistance to bleaching (mean diameter of unbleached corals=20 cm) and the most severe bleaching among larger corals (>29 cm diameter). By December, most of the larger colonies (mean diameter=40-49 cm) were pale white to light yellow although many also had patches of light brown tissue within the colony surface or along the margin. In particular, many of the *M. annularis* complex colonies had begun regaining color and were mottled in appearance. These colonies also exhibited extensive signs of recent mortality including the sudden emergence of a disease (a white syndrome resembling white plague). By August 2006, most corals had regained normal coloration. However, *M. annularis* colonies throughout the region experienced extensive partial and full colony mortality, and coral cover declined throughout the region by 40-60%.

On the east coast of Puerto Rico, bleaching was significantly more severe and prolonged at protected (leeward) reefs than at reefs under moderate or strong water circulation (Hernández-Delgado et al., 2006). Bleaching affected 80-97% of the corals at leeward reefs, 60-80% at reefs with moderate circulation and only 20-60% at exposed reefs with stronger water circulation (Figure 3.6). A total of 37% of surveyed coral species suffered a 100% bleaching frequency, 24% of the species suffered 80-99% bleaching, 29% of the species suffered 50-80% bleaching, and 10% suffered 20-50% bleaching (Figure 3.7).

Coral bleaching along the south and west coasts of Puerto Rico during late 2005 was particularly detrimental to coral reefs in which boulder star coral *(Montastraea annularis)* complex was the principal reef building species and dominant in terms of reef substrate cover. This includes some of the best coral reef systems of Puerto Rico in terms of live coral cover, such as those from Isla Desecheo (Puerto Canoas Reef, Puerto Botes Reef), and shelf-edge reefs off Ponce (Derrumbadero Reef), La Parguera (Boya Vieja Reef; García-Sais et al., 2006) and those from Mona Island (Hernández-Delgado et al., unpub. data). Coral mortality from these reefs was on the order of 50% (García-Sais et al., 2006). Reefs from the Tres Palmas system in Rincon, which are dominated by elkhorn coral (*Acropora palmata*) and great star coral (*M. cavernosa*) were the least affected by bleaching among reefs surveyed (García-Sais et al., 2006).

Bleaching was followed by a white plague-like massive outbreak that caused mass mortality and resulted in a net 20-60% decline in living coral cover at surveyed reefs of the east coast within a period of approximately six months. Nearly 100% of the colonies of important reef-building coral species such as *Montastraea annularis*, *M. faveolata*, *M. franksi* and *Acropora cervicornis* suffered significant partial colony mortality in Culebra Island (Figure 3.8). There was also a massive collapse of lettuce corals (*Agaricia* spp.) and cactus corals (*Mycetophyllia* spp.) at most reefs along the east, south and west coasts. The severe coral tissue loss and prolonged bleaching stress are also believed to be responsible for reproductive collapse during the 2006 spawning cycle, since physiological starvation from bleaching probably precluded coral gamete production (Hernández-Delgado et al., unpub. data).

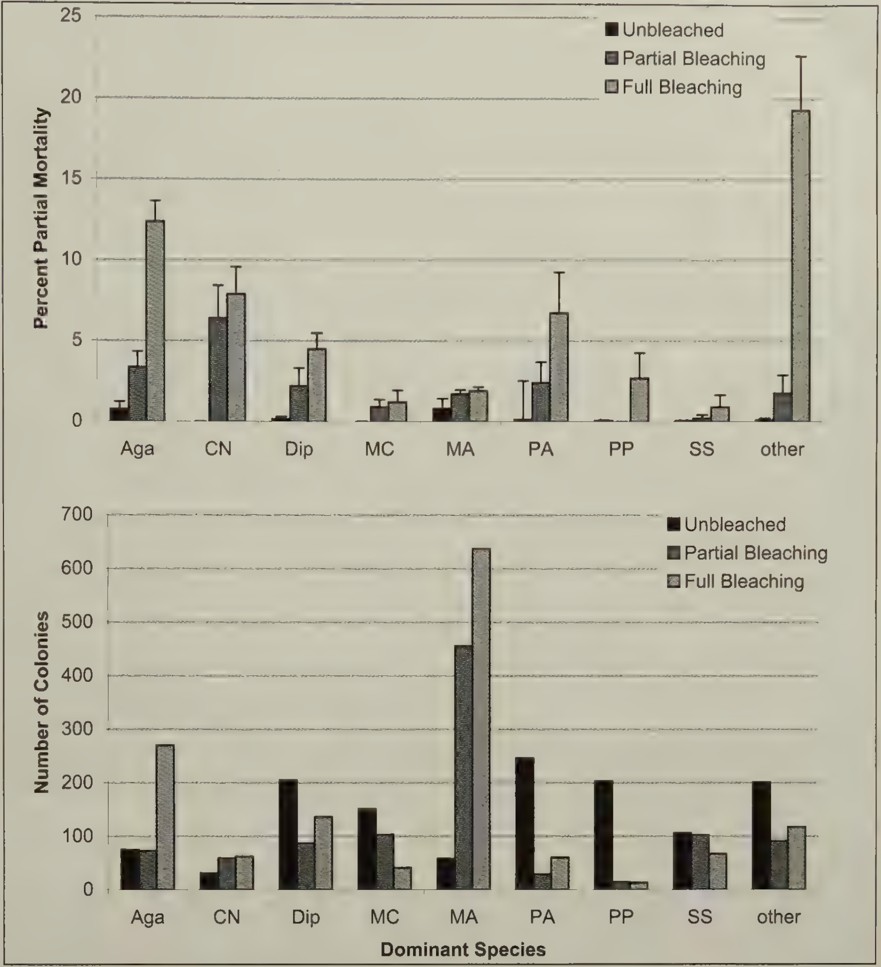


*Figure 3.5. Top panel shows relationship between bleaching severity and extent of recent partial mortality in December 2005 for dominant species observed in belt transects at all locations are pooled. Aga=*Agaricia *spp., CN=*Colpophyllia natans*, DIP=*Diploria *spp., MC=*Montastraea cavernosa*, MA=*M. annularis *(complex), PA=*Porites astreoides*, PP=*Porites porites*, SS=*Siderastrea siderea*, Other=16 other species of scleractinian and hydrozoan corals. Bottom panel shows number of unbleached, partially bleached and fully bleached colonies for dominant species observed in belt transects off southwest Puerto Rico (all sites and depths pooled). Source: Hernández-Delgado, unpub. data.*

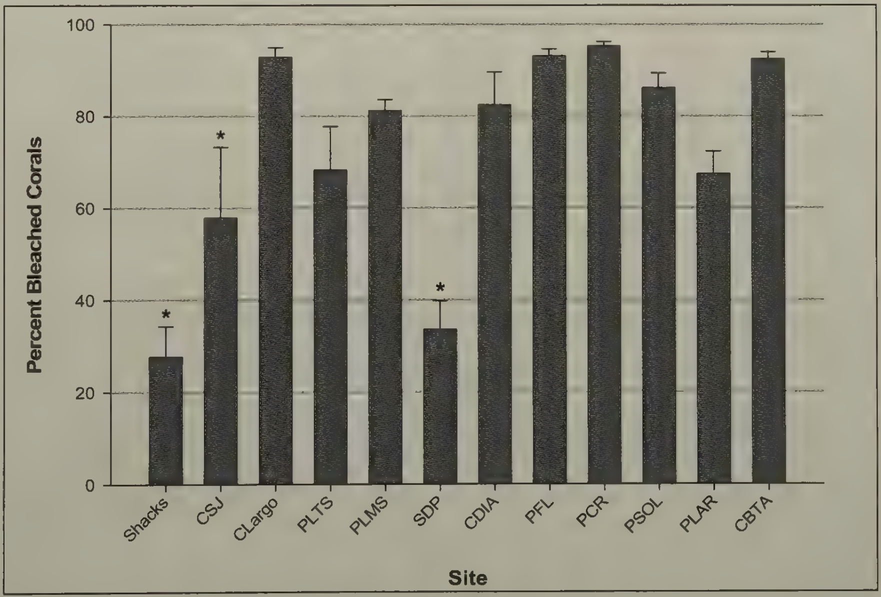


*Figure 3.6. Percent frequency of coral bleaching across Puerto Rico during 2005. Bars represent one standard error. Asterisks (*) indicate locations exposed to strong water circulation. Source: Hernández-Delgado et al., 2006.*

In La Parguera more than 40% of all coral colonies were bleached at eight of nine reefs surveyed; five of the reefs exhibited a bleaching prevalence higher than 50% and four had values higher than 70%. Higher prevalence of bleaching was found at intermediate distances to the coast and at intermediate depths. Among coral species from reefs in La Parguera, *Agaricia*, *Undaria*, *Montastraea*, *Colpophyllia*, *Acropora*, *Mycetophyllia*, *Millepora*, *Erythropodium* and *Briareum* were the most affected genera (Weil, unpub. data). Coral mortality was compounded by outbreaks of white plague type II (WP-II) and Caribbean yellow band disease (YBD) that primarily affected the *Montastraea* species complex right after the peak of the 2005 bleaching event. In Turrumote Reef, preliminary estimates indicate that colonies of *Montastraea* spp. lost an average of 50-60% of their live tissue at intermediate and deep habitats in the year after the bleaching-infectious disease (WPD) event began in 2005.

The sudden collapse of entire assemblages of several coral species at many reefs suggest the onset of a rapid Allee effect which could result in prolonged reproductive failure for reef-building species. Further, the continuous decline in percent cover of *Montastraea annularis* complex may have prolonged negative effects on their reproductive potential, sexual recruitment success and net reef accretion rates. Such unprecedented declines have already caused significant phase shifts in coral reef benthic community structure, presenting managers and decision makers with major challenges. These may include the need to develop aggressive and effective coral reef conservation-oriented management and research strategies aimed at dealing with unequivocal loss of resistance, resilience and ecological function.

The massive coral bleaching event throughout the Caribbean in 2005 has highlighted concerns regarding the sensitivity of coral reefs to climate change. Analysis of DHW, a parameter developed by NOAA's Coral Reef Watch for the estimation of the magnitude and duration of heat exposure for marine organisms, indicated sustained levels above or near the coral bleaching threshold during the period between August and November 2005. Satellite sensors documented the development of a coherent mesoscale structure with a SST water mass exceeding 30°C that traversed the northeastern Caribbean and impacted the southern coast of Puerto Rico. Sea surface height anomaly products by CCAR and Aviso both depict an anticyclone of approximately 14 cm that was spatially and temporally coincident with the zone of elevated SST.

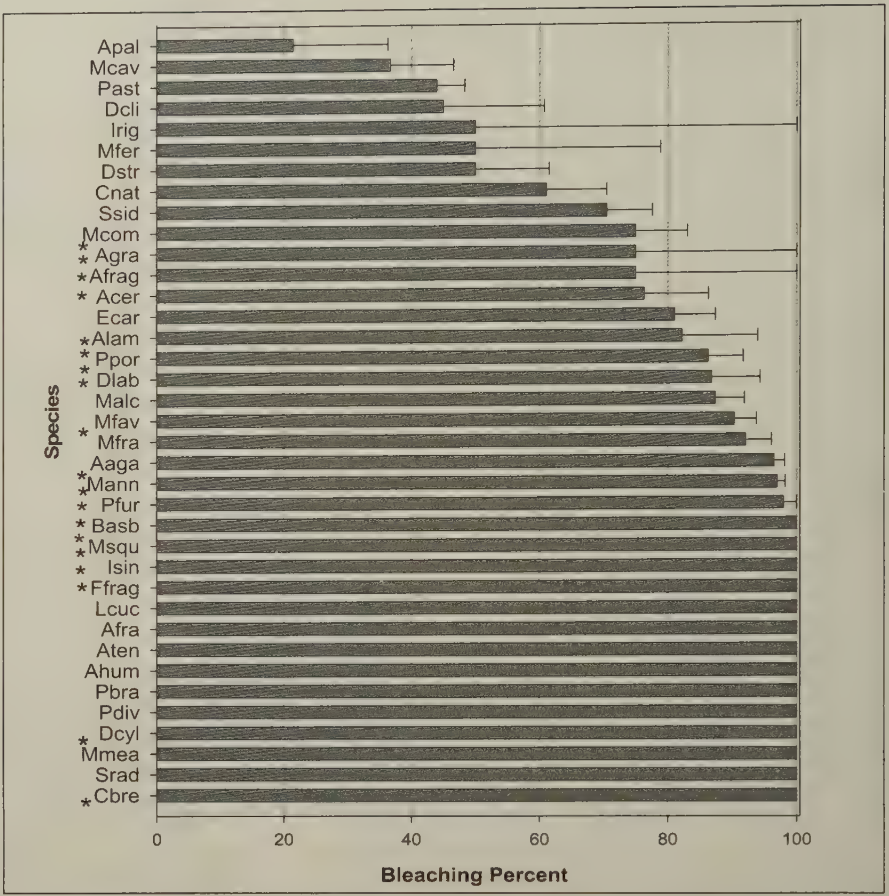


*Figure 3.7. Percent frequency of bleaching in coral species at 12 locations in Puerto Rico during 2005. Asterisks indicate important reef-building species. Apal*=Acropora palmata; *Mcav*=Montastraea cavernosa; *Past*=Porites astreoides; *Dcli*=Diploria clivosa; *Irig*=Isophyllastrea rigida; *Mfer*=Mycetophyllia ferox; *Dstr*=Diploria strigosa; *Cnat*=Colpophyllia natans; *Ssid*=Siderastrea siderea; *Mcom*=Millepora complanata; *Agra*=Agaricia grahamae; *Afrag*=Agaricia fragilis; *Acer*=Acropora cervicornis; *Ecar*=Erythropodium caribaeorum; *Alam*=Agaricia lamarcki; *Ppor*=Porites porites; *Dlab*=Diploria labyrinthiformis; *Malc*=Millepora alcicornis; *Mfav*=Montastraea faveolata; *Mfra*=Montastraea franksi; *Aaga*=Agaricia agaricites; *Mann*=Montastraea annularis; *Pfur*=Porites furcata; *Basb*=Briareum asbestinum; *Msqu*=Millepora squarrosa; *Isin*=Isophyllia sinuosa; *Ffrag*=Favia fragum; *Lcuc*=Leptoseris cucullata; *Afra*=Agaricia fragilis; *Aten*=Agaricia tenuifolia; *Ahum*=Agaricia humilis; *Pbra*=Porites branneri; *Pdiv*=Porites divaricata; *Dcyl*=Dendrogyra cylindrus; *Mmea*=Meandrina meandrites; *Srad*=Siderastrea radians; *Cbre*=Colpophyllia breviserialis. Source: Hernández-Delgado et al., unpub data.*

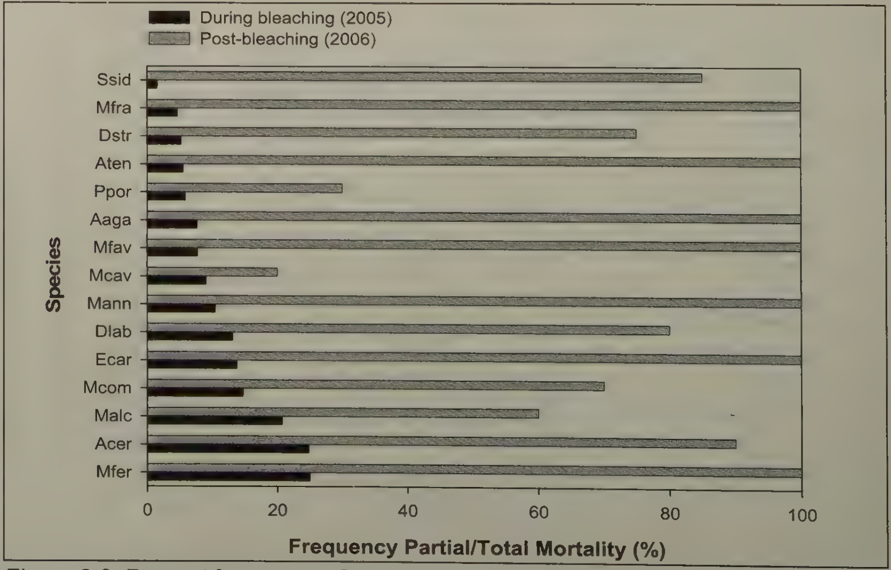


*Figure 3.8. Percent frequency of partial and/or total tissue mortality in selected coral species from Culebra Island during and six months after bleaching. Species codes provided in Figure 3.7 caption. Source: Hernández-Delgado et al., unpub. data.*

Anticyclonic eddies are recurrent features in the western tropical Atlantic and Caribbean basin. Four to five occur each year in the Caribbean with temporal scales of close to one month. Due to their clockwise circulation and Coriolis forcing, surface waters accumulate at the eddy center causing an increase in the mixed layer depth, which limits heat dissipation and exchange with surrounding water masses and results in a significant enhancement of the Ocean Heat Content. It is possible that the anticyclonic eddy is responsible for the observed DHW during the 2005 event. Anticyclonic eddies have recently been implicated in the acute intensity of Hurricane Katrina in the Gulf of Mexico and Hurricane Georges in the Caribbean.

## Diseases

Over the past several decades, coral reef communities around the world have experienced increasingly stressful conditions from a combination of natural and anthropogenic factors. These factors can act alone or in synergy, and may vary at different spatial and temporal scales (Figure 3.9). Bleaching and coral reef infectious diseases are two "natural" factors that have become major players in the deterioration of coral reef health (Hughes, 1994; Smith et al., 1996; Hoegh-Guldberg, 1999; Glynn et al., 2001; Miller et al., 2001; Weil et al., 2002; Richardson and Aronson, 2002; McClanahan, 2004; Weil, 2004; Ward et al., 2006). Coral reef disease research in Puerto Rico started a decade ago and has produced important information about the number, distribution, prevalence and impact of diseases/syndromes in several reef localities (Bruckner and Bruckner, 1997, 2006; Weil et al., 2002, 2003; Weil, 2004; Ballantine et al., 2005). The best studied areas include La Parguera and Guánica on the southwest coast, where well developed and extensive reefs are found, the Fajardo and Culebra area on the east coast, and reefs in the islands of Mona and Desecheo off the west coast.

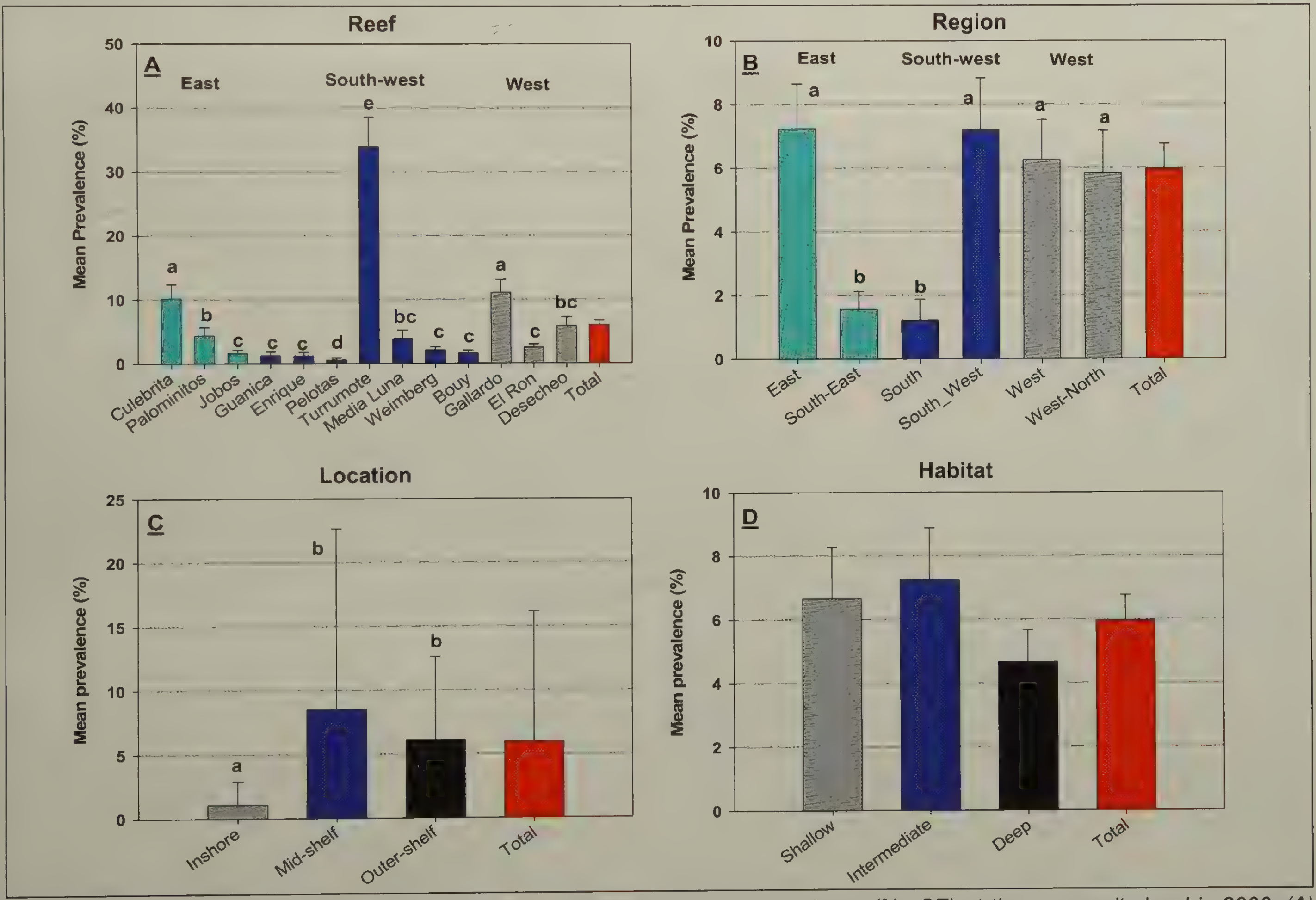


*Figure 3.9. Variability at different spatial scales of coral infectious disease prevalence (% ±SE) at the community level in 2006. (A) across reefs, (B) across geographic regions, (C) across location from near-shore to off-shore reefs and (D) habitats. The different letters above bars indicate significant differences (Kruskall-Wallis, p<0.05). Note different scales in the among graphs. Source: Weil et al., unpub. data.*

Most diseases or syndromes reported for the Caribbean are present in Puerto Rico, and frequent epizootics of WP-II, YBD, white band (WBD), white pox (patchy necrosis; WPX), bleaching and aspergillosis (ASP) continue to result in significant losses of coral cover (i.e., biomass and photosynthetically active surface area) in most reefs around the island (Figure 3.10). These epizootic events usually occur during the summer and fall and disappear during the winter when temperatures drop. Qualitative surveys of more than 100 coastal and offshore localities around the island during the last 25 years indicate a significant decline in populations of *Acropora* spp. in most localities, with minor ephemeral recovery at a few sites (Weil et al., 2003). A similar decline is now occurring within the *Montastraea* species complex, due largely to the effects of WP-II, YBD and bleaching in the last five years (Weil, unpub. data).

An island-wide survey was recently carried out to determine the status of diseases in coral reef communities. A total of 16 reefs were surveyed during summer of 2006. Using standard sampling protocols to assess the number, distribution and prevalence of diseases in corals, octocorals, sponges and crustose coralline algae (Weil et al., 2002). Overall, 16 different infectious diseases and syndromes were identified in Puerto Rican coral reef communities. Of these, 11 are affecting scleractinian corals, three are affecting octocorals, two are affecting zoanthids, at least two are affecting sponges and one is affecting crustose coralline algae. Bleaching, a non-infectious disease, has affected an increasing number of taxa in different biological groups in recent years (Figure 3.11). The most common diseases in Puerto Rico include some of the most infectious and damaging that have been described for the wider Caribbean (WP-II, YBD, WBD, Black Band Disease or BBD, ASP, Coralline white band or CCAWB and bleaching), but their distribution and prevalence is highly variable on spatial and temporal scales.

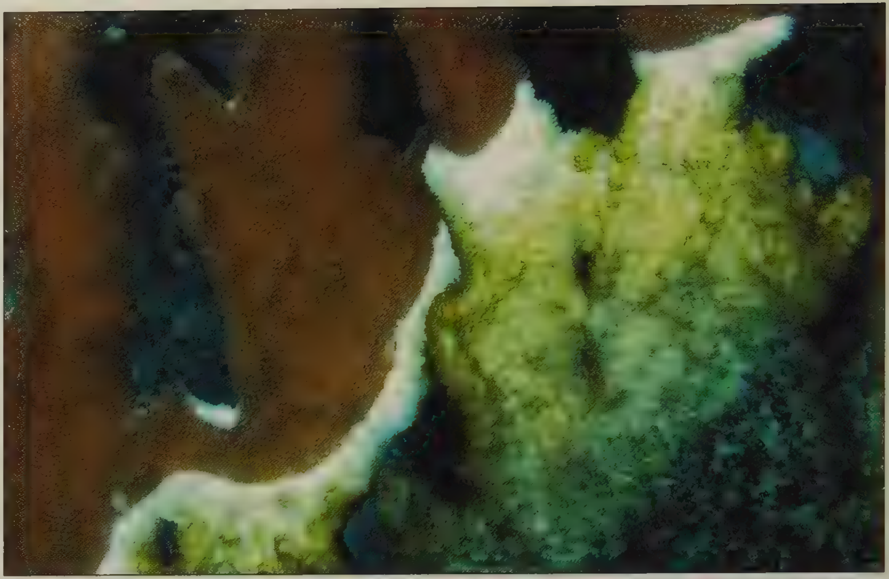


*Figure 3.10.* Acropora palmata *with the distinctive white band for which WBD is named. Photo: A. Bruckner.*

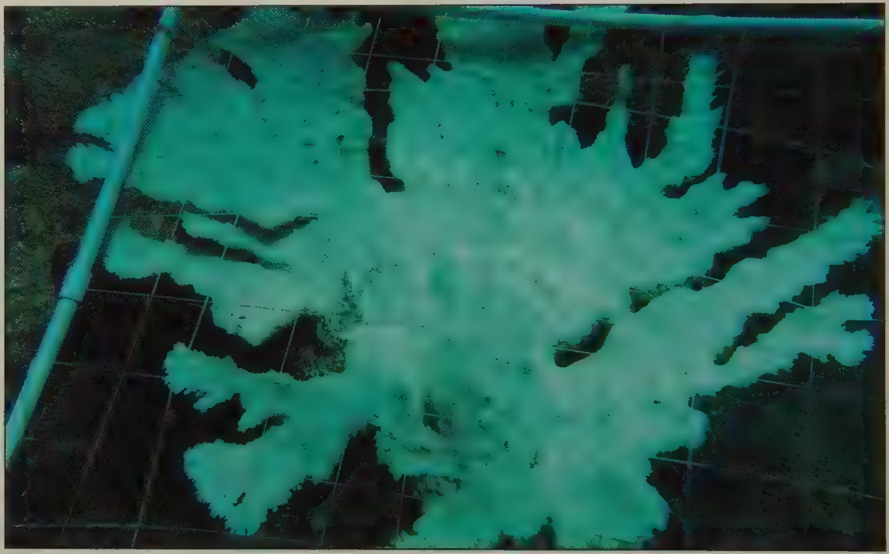


*Figure 3.11. Bleaching, such as in this colony of* Acropora palmata*, can increase the susceptibility of corals to disease. Photo: CCMA-BB.*

White Plague (WP) was first reported from La Parguera in 1995, and has since been observed throughout Puerto Rico and offshore islands, where it affects over 40 species of coral (Bruckner and Bruckner, 1997; Weil, 2004). This particular disease is considered one of the most damaging to coral populations because of its frequent outbreaks, wide range of hosts, and high virulence; WP can kill live coral tissue at rates that may exceed 1-2 cm per day (Weil, 2002; Weil et al., 2002; Weil, 2004). Since 1999, WP has been reported with increasing frequency from a growing number of shallow and deep reefs off La Parguera, Mona, Desecheo and Culebra. Most recently, in November and December 2005, extensive outbreaks of white plague affecting the genera *Montastraea*, *Diploria*, *Colpophyllia*, *Agaricia* and *Mycetophyllia* were observed.

WBD, the leading cause of mortality for Caribbean *Acropora* spp., was first reported in the early 1980s by Goenaga, who found that 20-33% of the *A. palmata* colonies at one reef near La Parguera were affected (Davis et al., 1986). Isolated cases of WBD were observed between 1995 and 2003, including an outbreak that affected 15% of the standing colonies on a reef off the east coast of Mona Island (Bruckner and Bruckner, 2006). WBD has also been observed among *A. cervicornis* populations near La Parguera in shallow nearshore locations and deeper shelf-edge reefs. A more virulent form of WBD was first documented among *A. cervicornis* colonies throughout Culebra in 2003, affecting 45% of all colonies on seven reefs (AGRRA, 2003). Recently, the more virulent form of WBD has been reported among inshore *A. cervicornis* nurseries and in reef environments around Culebra (E. Hernandez-Delgado, pers. comm.).

Another important source of mortality to *A. palmata* is WPX, also termed patchy necrosis and white patch disease. WPX is a widespread condition observed throughout southwest Puerto Rico since the mid 1990s (Bruckner, 2003; Weil, 2004). A large stand of *A. palmata* off Mona Island (Sardinera Reef) was first observed with WPX in 1996. Within two large permanent plots, 5-27% of the live colonies have been observed with this disease each summer through 2006. Affected colonies had multiple, irregular-shaped lesions 2-10 cm in diameter. Lesions were rapidly colonized by algae and cyanobacteria, expanding in size over a period of several years until the colony died completely. WPX was first observed at Carmelita, at the north end of the reef tract, in 2001. Initially, WPX showed a prevalence of 12%, which increased to 27% by May 2003 and to 40% by August 2005. Although WPX was rare (<0.1%) at both sites in February and December 2005, older lesions failed to heal at Sardinera and populations continued to decline, while affected colonies at Carmelita displayed rapid recovery, with new tissue and skeleton forming over old lesions. WPX has not been observed off the east coast of Mona.

Other diseases that have increased in abundance since 1999 on reefs near La Parguera, Desecheo and Mona Islands include YBD among *M. faveolata* and *M. annularis* and a "dark spots" disease on *S. siderea* and other species (Bruckner, unpub. data; Weil, 2004).The prevalence of diseases has been monitored annually on Mona Island since 1995, with emphasis on YBD. YBD was absent from these reefs in 1995 and was observed for the first time in 1996 among four colonies of *M. faveolata*. In 1999, YBD affected up to 50% of all *M. annularis* species complex colonies within permanent sites, including many of the largest (2-3 m diameter and height) and presumably oldest colonies. The highest prevalence of disease was recorded in shallow depths (3-10 m) off the protected west coast while fewer colonies were affected in deeper water (15-25 m) off the south coast. Measured rates of disease spread and tissue mortality has been slow (5-15 cm/year) compared to other diseases, although spatial, seasonal and annual differences were observed. Individual colonies with a single YBD lesion have exhibited multiple infections on the colony surface over time. With exception of those colonies with YBD that died, most corals first affected by YBD between 1999 and 2001 were still affected in 2003, with colonies losing 50-100% of their tissue over this period. The prevalence of YBD progressively increased in deeper sites over the last four years and this disease had been the greatest threat affecting the survival of *Montastraea* spp. populations until the massive coral bleaching event of 2005 that was associated with elevated SST.

Although incidences of black band disease (BBD) are rare, localized outbreaks have been recorded. BBD was first reported from Puerto Rico in 1972 (Antonius, 1973) and quantitative data was first collected in 1994 (Bruckner, 1999). Between 2002 and 2006, outbreaks were observed at shelf edge sites off La Parguera and off Mona Island among shallow habitats dominated by *Diploria* spp. BBD continues to affect massive and plating corals throughout the region, to depths of 30 m. Infections have been sporadic and uncommon (<0.5%), with a slight increase following the 2005 bleaching event and seasonal increases during summer and fall months.

## Tropical Storms

Hurricanes are natural, catastrophic events that have caused massive mortalities to coral reef and other coastal marine communities in Puerto Rico. In particular, hurricanes appear to be the main factor for the large-scale decimation of elkhorn coral (*Acropora palmata*) biotopes in Puertorrican reefs. The intense wave action, surge, and sediment abrasion associated with hurricanes cause the mechanical detachment and mortality of many benthic reef organisms, including corals in shallow reef zones. Coastal communities are also impacted by high sediment and nutrient loads from rainfall runoff during and for several days after the passage of hurricanes. Since the passage of Hurricane Georges in 1998, there have been no other major storms affecting coral reef ecosystems in Puerto Rico (Figure 3.12).

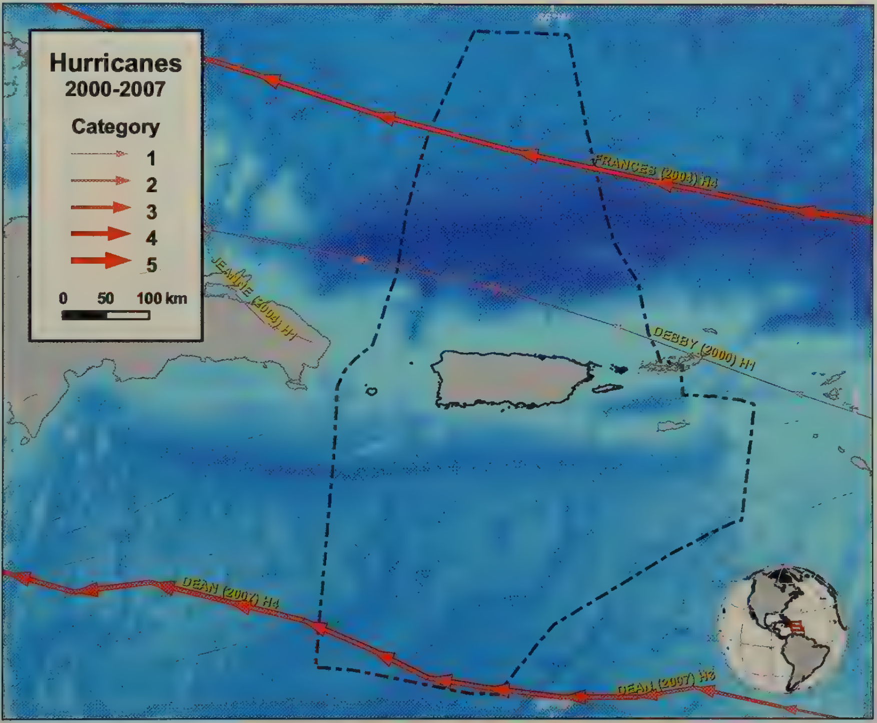


*Figure 3.12. The path and intensity of hurricanes passing near Puerto Rico between 2000-2007. Year of storm, hurricane name and storm strength on the Simpson scale (H1-5) are indicated for each. Map: K. Buja. Source: http://maps.csc.noaa.gov/hurricanes/.*

## Coastal Development and Runoff

In addition to permits issued for point and nonpoint source discharge by industries and wastewater treatment plants (discussed in the following section), the U.S. Environmental Protection Agency (EPA) issues Nonpoint Source Discharge Elimination System (NPDES) permits for construction activities on sites with more than 0.2 ha (0.5 acre). To date, problems with these permits have been the lack of knowledge on the part of developers regarding permit requirements, the lack of EPA personnel to inspect construction sites and ensure compliance, and the lack of implementation of adequate stormwater and erosion controls. Like the permits previously discussed, these require monitoring to ensure compliance with water quality standards. However, even when sites comply with NPDES permit requirements, stormwater and erosion control measures are often inadequate to ensure protection of downstream fishery habitat, including coral reefs.

In terms of impacts of coastal construction on the coral reef ecosystem in Puerto Rico, from October 2004 to September 2007, 336 water resources development projects were reviewed by the NOAA Fisheries Caribbean Field Office. Of these, an average of approximately 69 percent of the projects involved potential adverse interactions with fishery habitat (Carrubba, unpub. data). The construction of docks and piers, housing developments, and navigation projects, including marinas and maintenance dredging, were the most common type of projects proposed. Direct impacts that could result from the permitting of these projects included the elimination of seagrass beds, corals or coastal wetland, in particular mangrove forest for the construction of docks, piers and navigation projects. These projects also lead to indirect impacts such as increases in accidental groundings, propeller wash and propeller scarring associated with increased boating. Housing development projects typically involved proposed alterations to wetlands and channels, including the conversion of natural streams to concrete culverts and the filling of wetlands. Mitigation for many of the permitted projects, in particular those related to wetland impacts, is rarely successful as evidenced by site inspections of mitigations around Puerto Rico (Carrubba, pers. obs.; Roman, pers. comm.). Seagrass mitigation is also unsuccessful if the transplant location is not carefully selected and proper site preparation is not completed. Thus, water resources development projects around Puerto Rico have resulted in losses of wetlands and alteration of seagrass habitat, as well as alterations in hydrology. Hydrologic alterations affecting patterns of flow and nutrient and sediment transport, as well as the loss of coastal wetlands and seagrass beds that form natural filters minimizing the transport of materials to coral reefs, likely play an important role in the declining health of Puerto Rico's coral reef ecosystem. Recent efforts are now underway to try and link these causes and effects in order to better understand the role of land based activities and develop more effective management strategies to conserve marine resources.

### Coastal Pollution

Most industrial discharges around Puerto Rico include those associated with Regional Wastewater Treatment Plants (RWWTP) administered by the Puerto Rico Aqueducts and Sewers Authority (PRASA), thermoelectric power plants administered by the Puerto Rico Electric Power Authority, and private industry. These discharges are regulated by the EPA as part of their obligations under the Clean Water Act (CWA). The Puerto Rico Environmental Quality Board with oversight from EPA establishes the water quality standards with which these discharges need to comply. Monitoring requirements are a part of the permits issued for industrial discharges in order to ensure continued compliance with Puerto Rico's water quality standards.

For instance, EPA-mandated monitoring of zooplankton entrainment by the privately owned EcoEléctrica power plant is ongoing in Guayanilla Bay. Some of the major findings from this entrainment monitoring study are that (a) the mean daily flow rate of entrained seawater by EcoEléctrica during 2005 (28,921 $m^3$/day) represented approximately 0.0006 (or 0.06 %) of the Guayanilla Bay volume and 0.006 (or 0.6 %) of the "average" daily tidal flow exchange; (b) the mean daily entrainment of total zooplankton by the power plant represents about 0.3% of the "average" daily tidal exchange; and (c) the equivalent adult fish mortality (0.46 million individuals) represents 0.92% of the equivalent adult fish survival estimate for Guayanilla Bay. Based on these results, it is unlikely that entrainment will have a measurable ecological effect on zooplankton and the fish community in the bay at the present seawater entrainment flow rates (Vicente, unpub. data). Similar EPA mandated CWA 316 (a-b) studies are being performed for the thermoelectric power plants of Costa Sur, Guayanilla; Aguirre, Guayama; San Juan; and Palo Seco and Toa Baja, all of which are operated by PRASA. It should be noted that these monitoring programs are established based on permit requirements that address water quality standards, which are established to protect human health. Water quality standards are not necessarily appropriate for the continued maintenance of healthy coral reefs.

Due to continued concerns related to the discharge of thermal effluents that do not comply with water quality standards, in particular for PRASA plants in Aguirre and Guayanilla, EPA and PRASA are working toward an analysis of alternatives. EPA has declined to issue CWA waivers that would allow PRASA to continue violating water quality standards related to temperature. In Guayanilla, where the alternatives analysis process has been ongoing for a couple of years now, PRASA is considering the construction of a submarine outfall, as well as upgrades to the plant to reduce the temperature of the treatment water discharge. The discharge frequently exceeds the Puerto Rico water quality standard of 32.2°C (90°F), often reaching 43.3°C (110°F) in the summer months when energy demand is greatest. Ongoing modifications to the plant would lower the discharge temperature to 35.6°C (96°F). The Guayanilla discharge currently enters a thermal cove of altered mangrove wetlands, before passing into the waters of Guayanilla Bay. Even if the discharge is modified to meet current water quality standards, the standard is higher than the temperature for optimal coral growth and the maintenance of good coral condition.

RWWTPs operated by PRASA discharge primary treated effluents to the ocean via submarine outfalls. Four of these outfalls are located on the north coast (Carolina, Bayamon/Puerto Nuevo, Arecibo and Aguadilla), one is on the south coast (Ponce), and one is on the west coast (Mayagüez). The submarine outfalls of the north coast discharge within the insular shelf platform near the shelf-edge at depths that vary between 15 and 42 m. The Ponce outfall discharges at a depth of approximately 150 m on the insular slope and below the picnocline. Only the submarine outfall in the Ponce area is located in the vicinity of a shelf-edge reef; the other outfalls are in largely uncolonized benthic habitats. This discharge was relocated in an effort to improve nearshore water quality. Recently, problems with the discharge pipeline in Ponce led to renewed discharge of primary treated sewage in nearshore waters. In addition to the RWWTP, most of the smaller plants operated by PRASA in the coastal zone of Puerto Rico discharge primary or secondary treated effluent to streams, rivers or directly to the sea along the coast. Inland treatment plants also use streams and rivers as their discharge points. Over the past several years, there have been efforts to begin upgrading the smaller plants to advanced secondary treatment and connecting coastal communities to the sewer system rather than allowing the proliferation of septic systems in low-lying areas. Studies of intestinal bacteria in marine waters near small treatment plants indicate that bacterial contamination is common at low levels (Otero, unpub. data.)

### *NOAA Center for Coastal Monitoring and Assessment Contaminants Study in La Parguera*

Pollution has been identified as one of the major threats to coral reef ecosystems (Burke and Maidens, 2004; FDEP, 2004; Waddell et al., 2005), but the concentration of pollutants in and around coral reefs is not well characterized, and even less is known regarding linkages between individual pollutants and overall coral condition. Two projects are being conducted in Puerto Rico as part of an assessment framework developed by NOAA's CCMA, to quantify the relationship between chemical contaminants and coral condition. The first is in southwest Puerto Rico near the town of La Parguera; the second project is on the island of Vieques. The study areas were chosen based on established partnerships, data availability, and the need to characterize chemical contaminants and/or coral resources. Partners in the projects include NOAA, the University of Puerto Rico (UPR), Puerto Rico DNER, U.S. Fish and Wildlife Service (FWS), and the University of Hawaii.

#### *Methods*

In both projects, a stratified random sampling design was used for site selection in order to better characterize the distribution and concentrations of chemical contaminants in the study areas. In southwest Puerto Rico, 43 sites were sampled in August 2005 (Figure 3.13). In Vieques, approximately 45 sites were sampled in May 2007 around the entire island. Sediments were collected using either a sediment grab or by hand using divers. Coral tissues (*Porites astreoides*) were also collected. CCMA's National Status and Trends (NS&T) Program protocols were employed for sample collection and analysis, and in both studies over 150 organic (e.g., PAHs and PCBs) and inorganic (major and trace elements) contaminants were analyzed, some of which are listed in Table 3.1. The NS&T Program monitors chemical contamination in coastal waters of the U.S. and is a well documented, quality assured "industry standard" that has been in place since 1984. Additional information on sampling protocols can be found in Lauenstein and Cantillo (1993). On the island of Vieques, portions of which were used in the past for the storage and firing of munitions by the military, sediment samples were also collected and are being analyzed for another 15 compounds, termed "energetics". Results of the analysis of samples from Vieques will be available in early 2009. Results from the study in southwest Puerto Rico are discussed below.

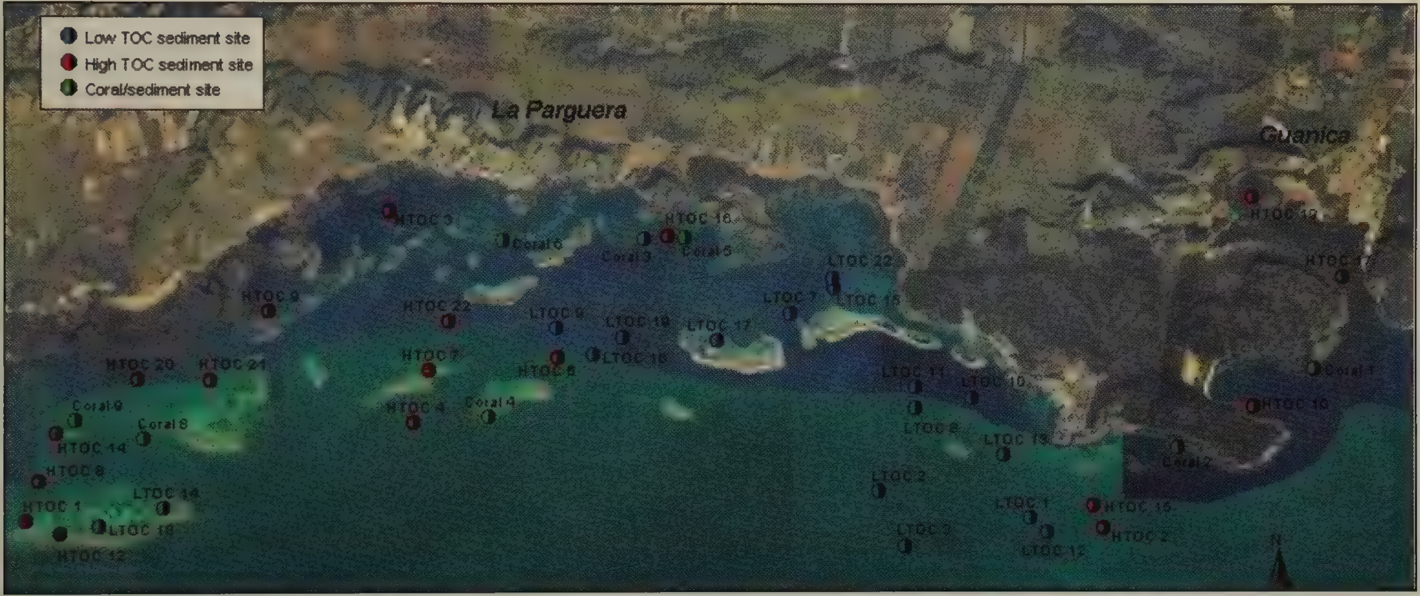


*Figure 3.13. La Pargurea contaminants study area sampling sites in southwest Puerto Rico. Source: Pait et al., 2007.*

#### *Results and Discussion*

Analysis of samples from southwest Puerto Rico indicated that, in general, the levels of both organic and inorganic chemical contaminants in the sediments and coral tissues were fairly low. At most sites around La Parguera, sediment contaminant concentrations were less than the national NS&T median values. A number of the contaminant classes indicated higher concentrations in embayments and behind emergent reefs, while concentrations at offshore sites tended to be lower. An example of the results from the analysis of sediments for polycyclic aromatic hydrocarbons (PAHs) is shown in Figure 3.14. PAHs are associated with the use and combustion of fossil fuels (e.g., oil and gasoline) and other organic materials (e.g., wood). Total PAHs as shown represents the sum of 24 of the PAHs analyzed by the NS&T Program. Elevated levels of PAHs were found adjacent to the town of La Parguera and at two sites sampled in Guanica Bay.

Results from the analysis of sediments for chromium are shown in Figure 3.15. A similar pattern was observed for this trace element, that is higher contaminant levels adjacent to the town of La Parguera and in Guanica Bay. At the two sites sampled in Guanica Bay (HTOC 17 and 19), chromium levels were over an order of magnitude higher than any of the other sites sampled, which may be related to some of the industrial activities that have occurred there over the years. The Effects Range-Median (ERM) is the concentration above which toxicity in test organisms is more frequently (50th percentile) observed. In Figure 3.15, the ERM value for chromium was exceeded at both sites in Guanica Bay indicating that toxicological effects on the aquatic biota in these areas are more likely. Additional details on the results of the sediment contaminant analyses can be found in Pait et al. (2007).

*Table 3.1. Selected chemical contaminants analyzed in southwest Puerto Rico and Vieques. Source: NOAA CCMA.*

| PAHS | PESTICIDES | PCBS | MAJOR AND TRACE ELEMENTS |
|---|---|---|---|
| Naphthalene | Aldrin | PCB18 | Aluminum (Al) |
| 1-Methylnaphthalene | Dieldrin | PCB28 | Antimony (Sb) |
| 2-Methylnaphthalene | Endrin | PCB31 | Arsenic (As) |
| 2,6-Dimethylnaphthalene | Heptachlor | PCB44 | Cadmium (Cd) |
| 1,6,7-Trimethylnaphthalene | Heptachlor-Epoxide | PCB49 | Chromium (Cr) |
| Biphenyl | Oxychlordane | PCB52 | Copper (Cu) |
| Acenaphthylene | Alpha-Chlordane | PCB56/60 | Iron (Fe) |
| Acenaphthene | Gamma-Chlordane | PCB66 | Lead (Pb) |
| Fluorene | Trans-Nonachlor | PCB70 | Manganese (Mn) |
| Anthracene | Cis-Nonachlor | PCB74/61 | Mercury (Hg) |
| Phenanthrene | Alpha-HCH | PCB87/115 | Nickel (Ni) |
| 1-Methylphenanthrene | Beta-HCH | PCB95 | Selenium (Se) |
| Fluoranthene | Delta-HCH | PCB99 | Silicon (Si) |
| Pyrene | Gamma-HCH | PCB101/90 | Silver (Ag) |
| Benz[a]anthracene | 2,4'-DDD | PCB110/77 | Tin (Sn) |
| Chrysene | 4,4'-DDD | PCB118 | Zinc (Zn) |
| Benzo[b]fluoranthene | 2,4'-DDE | PCB138/160 | -- |
| Benzo[k]fluoranthene | 4,4'-DDE | PCB146 | -- |
| Benzo[e]pyrene | 2,4'-DDT | PCB149/123 | -- |
| Benzo[a]pyrene | 4,4'-DDT | PCB151 | -- |
| Perylene | 1,2,3,4-Tetrachlorobenzene | PCB153/132 | -- |
| Indeno[1,2,3-c,d]pyrene | 1,2,4,5-Tetrachlorobenzene | PCB156/171/202 | -- |
| Dibenzo[a,h]anthracene | Hexachlorobenzene | PCB158 | -- |
| Benzo[g,h,i]perylene | Pentachloroanisole | PCB170/190 | -- |
| | Pentachlorobenzene | PCB174 | -- |
| **BUTYLTINS** | Endosulfan II | PCB180 | -- |
| Monobutyltin | Endosulfan I | PCB183 | -- |
| Dibutyltin | Endosulfan Sulfate | PCB187 | -- |
| Tributyltin | Mirex | PCB194 | -- |
| Tetrabutyltin | Chlorpyrifos | PCB195/208 | -- |
| | | PCB209 | -- |

Abbreviations: PAH, polycyclic aromatic hydrocarbon; PCB, polychlorinated biphenyl; HCH, hexachlorocyclohexane.

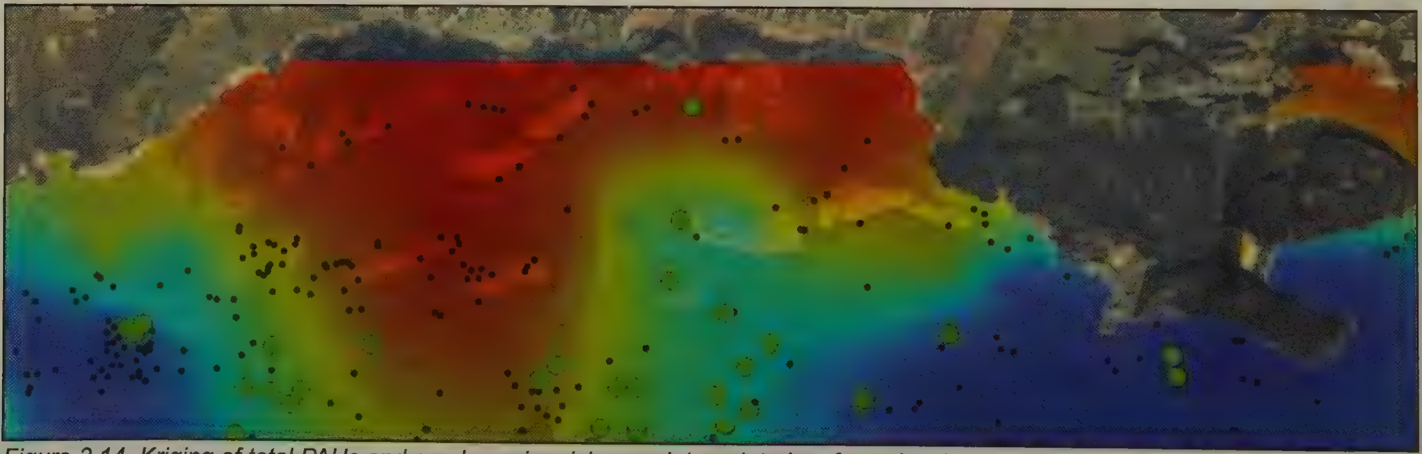


*Figure 3.14. Kriging of total PAHs and coral species richness. Interpolated surface showing high (red) to low (blue) concentrations of PAHs in the nearshore environment (p=0.0425). Black dots indicate survey points for NOAA's CCMA-BB. Green dots indicate locations where coral species richness was in the top 25th percentile. Source: NOAA CCMA.*

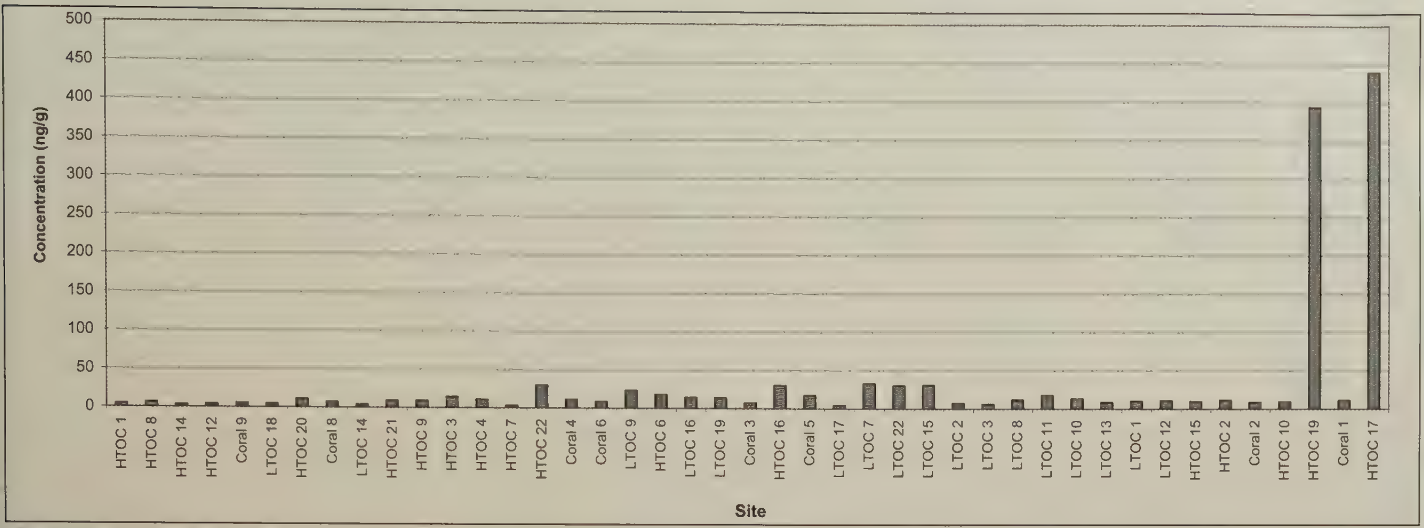


*Figure 3.15. Chromium levels, like many contaminants, displayed a pattern of higher concentrations nearshore, particularly in Guanica Bay, and lower concentrations offshore. Source: Pait et al., 2007.*

One of the major goals of the assessment framework is to establish linkages between chemical contaminants and coral ecosystem condition. To begin to address this goal, an exercise was conducted to look for correlations between PAH sediment concentrations and coral species richness in southwest Puerto Rico. A geospatial model was first constructed for the spatially autocorrelated PAH data. Existing mapped data on coral species richness from NCCOS' CCMA-BB was then overlaid on the modeled PAH concentrations. A nonparametric analysis of the modeled PAH data and coral species richness for the major reef building species indicated a strong negative correlation between modeled PAH concentrations and coral species richness, i.e., higher total PAH concentrations in the sediments were associated with lower coral species richness. The cause for the negative correlation between sediment PAHs and coral species richness is currently unknown. A variety of other physical, chemical and biological factors could be responsible for the observed pattern, in addition to the presence of contaminants. Efforts are currently underway to quantify contaminants and coral pathogens in the coral tissues from southwest Puerto Rico, which should provide more insight into the observed patterns of species richness. Future projects in southwest Puerto Rico, in Vieques, and in other parts of the Caribbean using the assessment framework will help scientists better understand how contaminants impact corals and coral reefs. By bringing the various data types and scientific expertise together in the assessment framework, an essential analytical capability is created that can be used to better assess the effects of chemical contaminants on corals and coral reefs, ultimately resulting in better management of these valuable and fragile ecosystems.

## Tourism and Recreation

DNER is currently in the process of completing a socioeconomic valuation of the coral reef ecosystem for the east coast of Puerto Rico in order to determine the value people place on these systems and efforts of scientists and educators to study and educate regarding these systems. The results of the study will be used to guide management and education and outreach efforts geared toward this part of the island, including Culebra and Vieques.

The effect of tourism activities upon coral reef systems in Puerto Rico is not well known. Tourism-related development continues to increase, especially in areas outside the metropolitan area of San Juan, as indicated in Figure 3.16. Due to constantly increasing numbers of personal watercraft, as well as the influx of boaters from other islands and the U.S., many of this development includes the construction of marinas or docks. A recent study by NOAA Fisheries and the U.S. Army Corps of Engineers in Fulladosa Bay, Culebra, at the Ponce Yacht and Fishing Club, Ponce and various areas in Florida, found that 63 percent of the docks in Fulladosa Bay were not authorized and their construction and use had resulted in the loss of at least 5 percent of the seagrass beds in the bay (Shafer et al., unpub. data). The dock in Ponce, although built with a type of grated decking, had resulted in the loss of a section of dense turtle grass due to shading from the dock, in addition to the loss of seagrass habitat due to dredging to accommodate larger vessels (Shafer et al., unpub. data). The increase in recreational vessels also

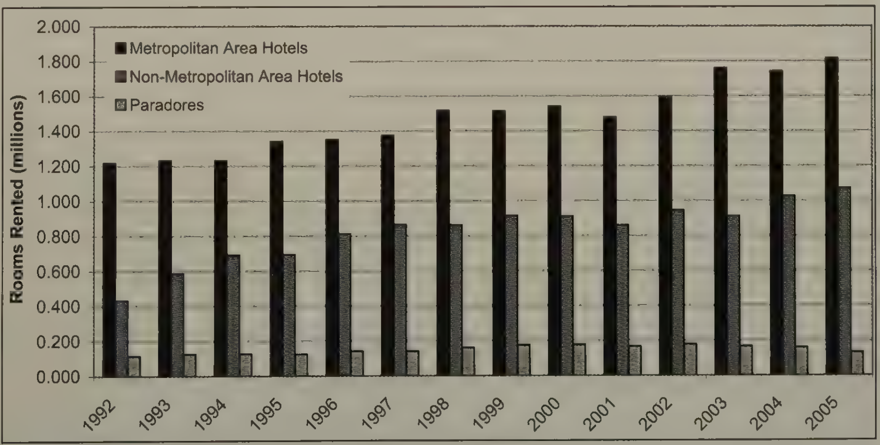


*Figure 3.16. Room occupancy for hotels and paradores between fiscal years 1992-2005. Source: Puerto Rico Tourism Co., 2005.*

leads to an increase in mechanical damage in seagrass beds. Carrubba et al. (2003) documented major propeller scar impacts in various locations in La Parguera Reserve, including shallows near Magueyes Island, and back reefs of Cayo Caracoles and Cayo Collado where 43-74% of the area potentially affected by boat traffic showed damage due to propeller scarring. In La Cordillera Reefs Natural Reserve, Otero and Carrubba (2007) found that impacts were concentrated in a few cays where boaters converge in order to access beaches. Based on estimates of probable and potential impact areas, at least 7, 14 and 21% of the seagrass habitats examined have been impacted in Palominito, Palomino and Icacos, respectively (Otero and Carrubba, 2007). In addition, the type of mechanical damage to seagrass beds from boats in Cordillera differed greatly than that observed in Parguera. Damages in Cordillera were almost exclusively due to anchoring in seagrass beds. Because boaters in Cordillera often have larger vessels than many of those in La Parguera and moor their vessels using a bow and a stern anchor, anchor damage is extensive in Cordillera in a few concentrated sites where recreational boaters congregate. Also, because boaters in Cordillera anchor with the stern of their vessel toward the shore in shallow waters, evidence indicated that some of the sandy bottom areas adjacent to popular beaches are barren of vegetation due in part to propeller wash.

In Puerto Rico, Law 430 of 2000, the Navigation and Aquatic Safety Law, and its associated Regulation 6979 of 2005, establish measures to protect the marine flora and fauna from recreational and other human activities. For instance, Article 24 of Regulation 6979 prohibits the mooring of any vessel in mangroves, coral reefs, or seagrass beds. The fine for violating this regulation is $250 and can be issued in the form of a ticket by any enforcement official (Article 35). The regulation also contains requirements related to the reporting of groundings. DNER is working to become more active in the documenting of recreational vessel groundings in order to characterize the cumulative impacts of these accidents on the coral reef ecosystem (Lilyestrom, pers obs.). However, a lack of enforcement and a serious lack of understanding on the part of the public, as well as regulatory and enforcement agencies regarding the importance of the coral reef ecosystem and reporting requirements has resulted in increases in accidental groundings of recreational vessels. NOAA ResponseLink data indicate that, from November 2007 to February 2008, 7 incidents caused by recreational vessels involving boat groundings with associated oil or gasoline spills were reported to the National Response Center. The incidents occurred in Joyuda, Mayagüez, Fajardo, Culebra, and San Juan. These incidents were apparently too small to result in activating a response under the Oil Pollution Control Act. The cumulative impacts to the reef environment of small spills and recreational vessel groundings is currently understudied and therefore unknown in Puerto Rico.

According to the Puerto Rico Tourism Company (PRT, 2005), between 2002 and 2005 the occupancy rate in hotels and "paradores" fluctuated between 2.72 and 3.02 million rooms. The total room occupancy has maintained a gradually increasing rate from 1992 to 2005 (Figure 3.16). Approximately 60.1% of the total room occupancy has been concentrated within the San Juan metropolitan area, where coral reefs do not occur. However, tourists staying in San Juan often travel to the northeast, south and southwest coasts to participate in SCUBA diving charters and other marine recreation activities. The diving charter industry is at the forefront in terms of coral reef protection policies and is active and highly visible in many activities organized for coral reef protection. In most instances, diving charters do not allow spearfishing during diving expeditions and emphasize coral reef protection. The effect of anchoring by relatively large diving vessels was a problem that has been significantly improved by the installation of mooring buoys by the DNER in the most heavily visited dive sites.

## Fishing

In the coastal waters of Puerto Rico, authority for fisheries management from the shoreline to nine 16.7 km is with the Commonwealth of Puerto Rico, while the CFMC is responsible for fisheries management in federal waters extending from 16.7 km to 370.4 km (the Federal Exclusive Economic Zone or EEZ). The fish, of course, do not recognize these boundaries, and most stocks are managed jointly. Efforts to achieve consistency in fisheries management have resulted in regulations such as a total prohibitions on the harvest of Nassau and goliath groupers, seasonal closures to protect spawning aggregation sites for groupers and snappers, bans on certain gears in particular locations (e.g., three area closures off the west coast of Puerto Rico), and size (spiny lobster, queen conch, yellowtail snapper) and bag limits (queen conch, dorado) for species caught from the shoreline to the EEZ.

Commercial and recreational fisheries land over 179 edible fish species, as well as numerous species for the ornamental and aquarium trade. Commercial fishing is conducted inshore and offshore from both large and small boats, with gear including traps and pots, bottom longlines, and gill and trammel nets. Hook-and-line recreational fishing is conducted from shore, or from charter, rental or privately-owned boats, while recreational divers may capture spiny lobster by hand or reef fish by spear. Most species caught are associated with coral reef habitats, and the harvest is shared by commercial (artisanal) and recreational fishers. Some species are caught primarily by the recreational fishery (including surgeonfishes, angelfishes, tilefish and jacks), others are shared approximately equally among the commercial and recreational sector (red hind, queen snapper), and some are caught primarily by the commercial fisheries, including silk snapper, yellowfin grouper, squirrelfish, parrotfishes, spiny lobster and queen conch. Of these species, the vast majority are harvested from the insular shelf, except in the case of deep water snappers (e.g., silk, and queen), which have become popular with the recreational fishers and are harvested at depths between 60 and 560 m.

In 2005, the CFMC amended several Fishery Management Plans with measures to improve the collection of fishery-dependent data and to group reef fish species into Fishery Management Units or FMUs (CFMC, 2005) based mostly on local expert knowledge. Total landings by FMU for the years in which there are data available are compared for both the commercial and recreational sectors in Table 3.2, excluding pelagic species (dorado, mackerels, tunas, sharks), near-shore species such as tarpon and snook, mojarras, sardines and other baitfish reported in the catches. Figure 3.17 shows that in four of the six years, reported recreational total landings were higher than commercial landings, despite the fact

*Table 3.2. Reef fishery landing averages for Puerto Rico (in pounds). Commercial landings were averaged for the period between 1997 and 2001. Recreational landings were averaged for the period between 2000 and 2001 Source: CFMC, 2005.*

| STOCK | Commercial Landings | Recreational Landings | TOTAL | Commercial Allocation | Recreational Allocation |
|---|---|---|---|---|---|
| **SNAPPER** | | | | | |
| Unit 1: (black, blackfin, silk, vermilion, unc) | 267,089 | 153,274 | 420,363 | 64% | 36% |
| Unit 2: (queen, wenchman) | 72,244 | 60,612 | 132,856 | 54% | 46% |
| Unit 3: (gray, lane, mutton, dog, schoolmaster, mahogany) | 360,080 | 117,548 | 477,628 | 75% | 25% |
| Unit 4: (yellowtail) | 298,845 | 24,135 | 322,980 | 93% | 7% |
| **GROUPER** | | | | | |
| Unit 1: (Nassau) | 16,241 | 3,772 | 20,013 | 81% | 19% |
| Unit 2: (goliath) | 61 | 6,169 | 6,230 | 1% | 99% |
| Unit 3: (hind, red, coney, rock, graysby, crolefish) | 75,050 | 55,266 | 130,316 | 58% | 42% |
| Unit 4: (red, misty, tiger, yellowfin, yellowedge, unclassified) | 61,535 | 21,309 | 82,844 | 74% | 26% |
| **REEF FISHES** | | | | | |
| Grunts: (white, porkfish, margate, bluestriped, french, tomtate) | 134,898 | 19,051 | 153,949 | 88% | 12% |
| Goatfish: (spotted, yellow, unc) | 20,587 | 1,510 | 22,097 | 93% | 7% |
| Porgies: (jolthead, sea bream, sheepshead, pluma, unc) | 31,102 | 2,887 | 33,989 | 92% | 8% |
| Squirrelfish: (bigeye, longspined, unc, blackbar, soldierfish) | 14,924 | 6,593 | 21,517 | 69% | 31% |
| Tilefish: (blackline, sand, unc) | 514 | 1,765 | 2,279 | 23% | 77% |
| Jacks: (blue runner, horse-eye, black, almaco, bar, greater amberjack, yellow, unc) | 83,411 | 167,140 | 250,551 | 33% | 67% |
| Parrotfishes: (blue, midnight, princess, queen, rainbow, redfin, redtail, stoplight, redband, striped, unc) | 92,207 | 29,214 | 121,421 | 76% | 24% |
| Surgeonfish: (blue tang, ocean, doctorfish, unc) | 8 | 630 | 638 | 1% | 99% |
| Triggerfish: (filefish, scrawled, whitespotted; triggerfish: ocean, black, sargassum, queen, unc) | 58,781 | 74,355 | 133,136 | 44% | 56% |
| Boxfish: (cowfish: honeycomb, scrawled; trunkfish: spotted, smooth) | 83,271 | 4,257 | 87,528 | 95% | 5% |
| Wrasses: (unc, spanish hogfish, puddingwife) | 58,485 | 7,417 | 65,902 | 89% | 11% |
| Angelfish: (queen, gray, french) | 71 | 1,278 | 1,349 | 5% | 95% |
| **FINFISH TOTAL** | **1,729,404** | **758,182** | **2,487,586** | **70%** | **30%** |
| **LOBSTER** | | | | | |
| Lobster: (spiny, spotted) | 290,555 | 135,633 | 426,188 | 68% | 32% |
| **CONCH** | | | | | |
| Conch | 248,437 | 132,121 | 380,558 | 65% | 35% |
| **GRAND TOTAL** | **2,268,396** | **1,025,936** | **3,294,332** | **69%** | **31%** |

that reported recreational landings do not include any information on queen conch, spiny lobster or other shellfish harvested by recreational fishers. Commercial fishers have been voluntarily sharing landings data since 1967 and by law since 2005 (Juhl and Cabro, 1972); recreational harvest data is primarily from the Marine Recreational Fisheries Statistics Survey (MRFSS), which has been conducted in Puerto Rico since 2000 (NMFS, 2007). Data from this program is available at http://www.st.nmfs.noaa.gov/st1/recreational/overview/overview.html.

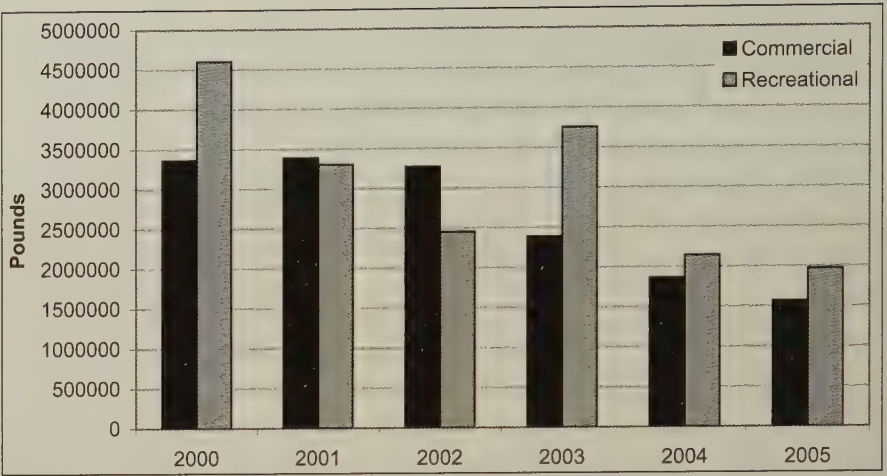


*Figure 3.17. Reported landings for Puerto Rico between 2000 and 2005. Sources: NMFS Commercial Fishery Statistics Program and MRFSS database.*

Recognizing that there are problems with the commercial and recreational catch databases, with under-reporting being a primary concern, the Puerto Rico DNER has included a correction factor that varies from year to year for commercial fisheries. The landings were thus adjusted by 0.50 and 0.86 for the commercial fisheries between 2000 and 2005 (D. Matos-Caraballo, pers. comm.; Matos-Caraballo 2004b). Figure 3.18 shows a comparison between the uncorrected commercial data, corrected commercial data and the recreational catch data from 2000 to 2005. Users of catch data from these sources should be cautious in how it is applied, given the concerns about over reporting and misreporting in addition to the use of data correction factors.

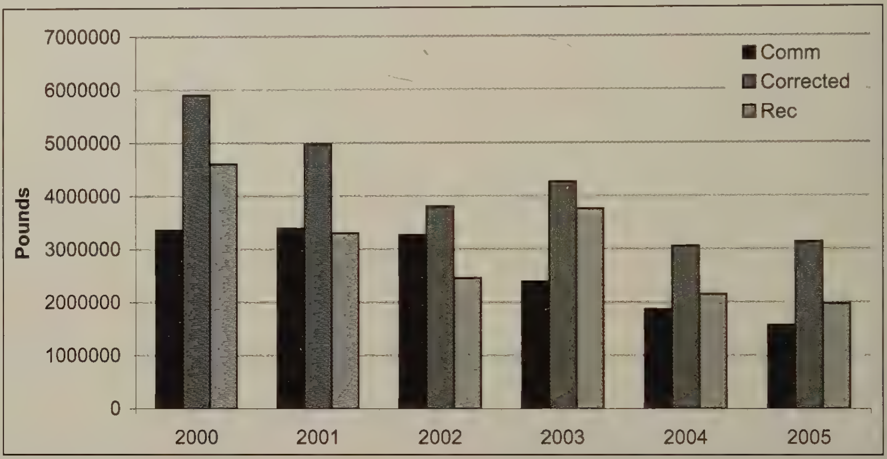


*Figure 3.18. Commercial, corrected commercial and recreational landings in Puerto Rico between 2000 and 2005.Sources: NMFS Commercial Fishery Statistics Program and MRFSS database.*

The recreational fisheries data from MRFSS also has potential sources of error, since the catch weights that are used to estimate total recreational catch are obtained mostly from telephone interview surveys. In spite of the sources of error in the data, the trends represented in the data need to be taken seriously in light of the cumulative impact that an uncontrolled recreational fishery could have on reef-associated fishery resources. The removal of juvenile fish, queen conch, lobster and the herbivorous fish that help maintain healthy coral reefs is of particular concern.

*Table 3.3.* MRFSS summary data for 2000-2006 for all fish species by mode reported for Puerto Rico (LBS=pounds of fish, Trips=number of trips reported). Source: MRFSS database.

| | | **MODE** | | | |
|---|---|---|---|---|---|
| | | **CHARTER** | **PRIVATE** | **SHORE** | **TOTAL** |
| 2000 | LBS | 48,173 | 4,195,832 | 357,736 | **4,601,741** |
| | TRIPS | 16,899 | 522,914 | 792,890 | **1,332,703** |
| 2001 | LBS | 23,281 | 2,752,165 | 526,476 | **3,301,922** |
| | TRIPS | 10,919 | 504,349 | 896,675 | **1,411,943** |
| 2002 | LBS | 22,438 | 2,236,507 | 193,103 | **2,452,048** |
| | TRIPS | 34,227 | 572,844 | 693,938 | **1,301,059** |
| 2003 | LBS | 28,254 | 3,320,974 | 405,735 | **3,754,963** |
| | TRIPS | 21,764 | 471,741 | 617,900 | **1,111,405** |
| 2004 | LBS | 40,435 | 1,940,892 | 164,148 | **2,145,475** |
| | TRIPS | 22,028 | 389,469 | 638,802 | **1,050,299** |
| 2005 | LBS | 41,689 | 1,835,863 | 93,711 | **1,971,263** |
| | TRIPS | 17,969 | 379,910 | 468,843 | **866,722** |
| 2006 | LBS | N/A | N/A | N/A | **N/A** |
| | TRIPS | 16,906 | 386,111 | 493,565 | **896,582** |

***Recreational Fisheries***

The MRFSS database also includes information on the various modes that make up the recreational fishing sector including charter boat operations, shoreline fishing and the private/rental boat sector. Table 3.3 and Figure 3.19 summarize the data available for each of the modes (charter, shore and private) for the years 2000 to 2005. The private recreational mode, which includes boat owners or rentals, but not charters or for-hire vessels, had 88 to 93% of the harvest from 37 to 44% of the trips taken. The shoreline fishers accounted for 4 to 10% of the catch from 53-60% of the trips taken, and the charter operations accounted for 1 -2% of the total catch from 2% of the trips taken per year. The MRFSS includes both local and out-of-state fishers; in Puerto Rico, the ratio is about 4:1 local to out-of-state. This could indicate that the amount of fish being harvested exceeds the regulatory limit for recreational catch. In 2004, DNER established limits for the recreational harvest of several species (i.e., bag limits; Puerto Rico Fishing Regulation #6768, February 11, 2004), and instituted requirements for licenses and permits. The regulations include a total prohibition on the harvest of goliath and Nassau groupers. Licenses and permits have not been implemented, thus the number and true impact of recreational fishers in Puerto Rico continues to be unknown.

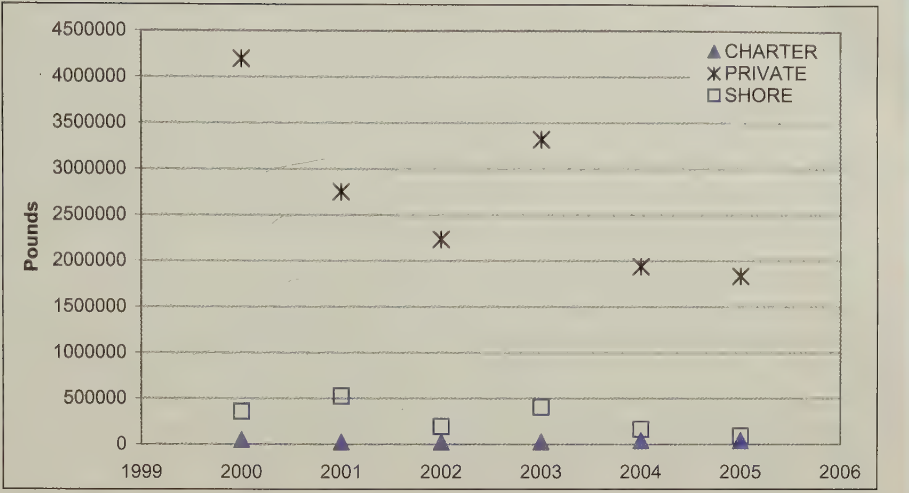


*Figure 3.19. Recreational landings in Puerto Rico, 2000-2006. Source: MRFSS database.*

### Commercial Fisheries

There were 1,163 active commercial fishers in Puerto Rico in 2002, (Matos-Caraballo, 2004a) utilizing 956 fishing vessels with lengths of 5-9 m (about 15-30 ft). The number of active fishers varied by about 500 individuals between 1996 (1,758 active fishers) and 2002. Commercial fishers have been reporting catches since 1967 and provide their landings by gear type (Figure 3.20; D. Matos-Caraballo, unpub. data; Matos-Caraballo, 2004b). The commercial catch data indicate that all gear types have been used to harvest the 27 family groups (groupers, snappers, goatfish, etc.) recorded in the database; specific information on over 24 species (e.g., red hind, silk snapper, spotted goatfish, queen triggerfish; Matos-Caraballo 2004b) is also provided. Since the 1990s, the primarily trap-based fishery of Puerto Rico has been replaced by a bottom line fishery that uses multiple hooks on each weighted line. Increases in the harvest of deep water snapper species and pelagic fish such as dorado have been most noticeable. Although landings for the top families (snappers, groupers and grunts) have remained stable, changes in species-specific landings have been reported, such that silk and queen snappers have become the top landed species. Since the 1990s, pelagic species (e.g., tunas, dorado or mackerels) have ranked among the top three species-groups landed. Thus, shifts in fishing methods and species collected, taken together with the overall decline in landings, have refocused the commercial fisheries of Puerto Rico from a shallow-water, coral reef-associated trap fishery to a fishery associated with pelagic and deeper reef species. However, the diversity of the catch composition persists.

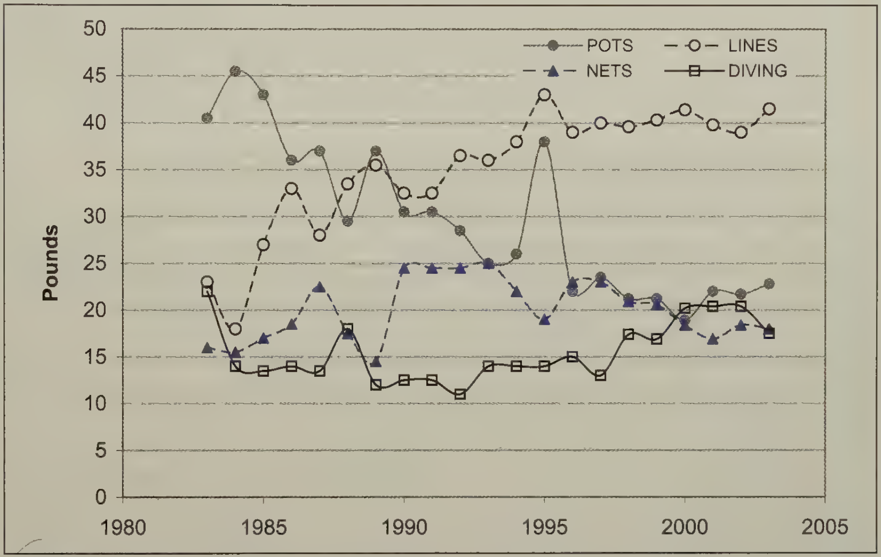


*Figure 3.20. Percent commercial landings by gear in Puerto Rico from 1983 to 2004. Source: Matos-Caraballo, pers. comm.*

Several important changes are evident in the fisheries of Puerto Rico over recent decades. The abundance of shallow water reef fish and associated species have generally declined, with possible causes including overfishing, changes in nearshore habitats (sedimentation, eutrophication and pollution), higher SSTs associated with bleaching and coral diseases, increased use of marine resources by boaters, recreational fishers, etc. Overfishing has been implicated in the decline in landings observed among coral reef-associated fish and shellfish species. The documented trends have recently resulted in determinations that Nassau and goliath groupers (*Epinephelus striatus* and *E. itajara*) and queen conch (*Strombus gigas*) are being overfished (CFMC, 2005). The trends also indicate that overfishing occurs in Snapper Unit 1, Grouper Unit 4 and the parrotfish complex (Table 3.2; CFMC, 2005). Bycatch occurs within Puerto Rico's commercial and recreational fisheries, but its impact on local fish populations is not fully known. Types of bycatch include regulatory discards such as yellowtail snapper less than 12 inches TL (total length – from tip of snout to tip of tail), or discards that occur because the fishes are potentially ciguatoxic (e.g., great barracuda) or simply not marketable (e.g., butterflyfishes; Matos-Caraballo, 2005). Although difficult to document, commercial fishers have claimed that the declines in fisheries are a result of habitat loss and degradation, which has reduced recruitment of larvae and juveniles to the population. Fishing communities are being impacted by changes to marine habitats, development of the coastline and overfishing. Management urgently needs to better monitor commercial and recreational fisheries, assess the impacts of environmental factors on fisheries, and enforce existing fishing and environmental regulations.

In response to concerns over declines in some reef fish species, in 1996, the CFMC, in cooperation with the Puerto Rico DNER and the commercial fishermen of the west coast, took action to protect deep reefs that are known spawning aggregation sites for red hind (*Epiniphelus guttatus)* in three areas off Puerto Rico's west coast (CFMC, 1996). At the request of the commercial fishers and with the recommendation of the CFMC's Reef Fish Committee, the CFMC established seasonal closures at Bajo de Sico, Tourmaline Bank and Abrir La Sierra to protect spawning sites for this grouper species, which is important for commercial and recreational fisheries (Figure 3.1). Each closure measures 16.7 $km^2$ and prohibits all fishing from December 1 to February 28. Additionally, in 2005, the use of all bottom-tending gear (traps, pots, bottom longlines or gill and trammel nets) was prohibited from these areas year-round (CFMC/NMFS, 2005).

The Southeast Area Monitoring and Assessment Program for the Caribbean (Rosario, 1996), a fishery-independent biological survey, together with anecdotal information provided by commercial fishers, were used to locate red hind spawning aggregations in Bajo de Sico and Abrir La Sierra (A. Rosario, pers. comm.). Initial characterization of the deep reefs in these areas was completed in 2004 (García-Sais et al., 2005b). Detailed high resolution bathymetric surveys of all three closed areas were conducted jointly by the CFMC and CCMA-BB with support from the NOAA Coral Reef Conservation Program (CRCP) in 2007. The surveys yielded the first video footage of an extensive deep hermatypic reef system at depths between 50-90 m (NOAA, 2007; http://ccma.nos.noaa.gov/products/biogeography/usvi_nps/2007/updates/april.html). Plans are in place to complete the seafloor characterization and bathymetric surveys of these areas during the next visit of the NOAA ship *Nancy Foster* in the spring of 2008.

Puerto Rico's commercial fishers from the west coast have also provided valuable information on the location of deep water populations of queen conch (*Strombus gigas*) in Abrir La Sierra. The queen conch fishery in federal waters off the west coast of Puerto Rico was closed in 2005 (CMFC/NMFS 2005). Although such regulations exist, little monitoring is conducted in closed areas, and additional research is needed to document changes to the population post-closure.

## Trade in Coral and Live Reef Species

Puerto Rico laws and regulations allow only for the collection of small pieces of dead coral (small enough to fit in the palm of your hand) as souvenirs from beaches around the island. The collection of live or dead coral for scientific purposes requires a permit from DNER. Similarly, artisans with a valid DNER permit can collect dead coral from beaches for use in their works of art. At this time, only about five artisans around Puerto Rico possess this permit (DNER, unpub. data). Federal regulations also prohibit the collection of live or dead coral within federal waters except for scientific purposes and with authorization from the CFMC. Recently, NOAA Office of Law Enforcement and NOAA Fisheries Caribbean Field Office have been working with the Transportation Security Administration (TSA), Homeland Security (Customs and Border Patrol), and DNER Rangers to address the ever larger problem of coral souvenir collection. With the opening of the Aguadilla and Ponce airports to commercial flights from the U.S., the unauthorized transport of corals in luggage has increased dramatically, although it is also a problem in the San Juan airport. TSA reported one tourist as having a suitcase weighing more than 60-pounds of which most of the weight was composed of coral heads traveling through the Aguadilla airport. The tourist explained that she was taking the coral heads home to be used as door stops. DNER Rangers in Ponce report regular transport of pieces of coral, as well as undersized queen conch shells, which are also prohibited for possession. TSA in San Juan report that they regularly process suitcases with 15-35 pounds of coral packed as souvenirs of the trip to Puerto Rico. In January 2008, a tourist was stopped in the San Juan airport with a suitcase full of still wet finger coral, most of which had live tissue at the time of the intervention. Because of this increasing problem, NOAA Fisheries has begun a campaign through a local tourism program and signs in airports and the CFMC and NOAA Office of Law Enforcement are also planning educational campaigns. NOAA is also working closely with TSA to train officers in the identification of corals and interventions with persons in possession of these souvenirs.

Staghorn coral, which is now listed as threatened under the ESA, is one of the corals being collected as a souvenir. On December 14, 2007, NOAA Fisheries published a proposed rule to extend ESA Section 9 prohibitions to elkhorn and staghorn corals. Under this rule, these corals would be treated as endangered species and their collection, possession, harm, take, intent to take, sale, etc. would be prohibited. Only scientific and educational activities with appropriate authorization would be permitted for this species. Thus, if unauthorized souvenir collection continues at its current rate, enforcement may involve federal ESA penalties if the persons are convicted. This may assist in curbing the current souvenir collection as current regulations have not proven sufficient.

## Ships, Boats and Groundings

Since the 326-foot freighter M/V *Fortuna Reefer* ran aground on the southeast coast of Mona Island on July 24, 1997, scientists have continued to monitor the condition of 1,857 fragments of elkhorn coral (*Acropora palmata)* that were reattached to the substrate as part of a restoration effort. Fragments experienced high rates of early mortality (57% surviving after two years), with losses attributed primarily to wire breakage and removal during winter storms, overgrowth by bioeroding sponges, disease and predation by corallivores (*Coralliophila abbreviata* gastropods). After nine years (August, 2006), 10% (n=185) of the original fragments are still alive and now resemble adult colonies, with extensive branching patterns and substantial increases in height (mean=39 cm tall). They range in maximum diameter from 15-300 cm (mean=76 cm), with larger fragments attached to the reef (mean=79 cm versus 68 cm). Roughly half of these have live tissue covering most of their skeletal surfaces, and they have produced numerous new branches (48%, mean=five branches/coral, 89 cm in length), although only 21% (n=39) have accreted tissue and skeletal material onto the substrate and are firmly attached. Most surviving fragments are attached to the reef (n=129; 70%), and are oriented upright (n=108), although fragments attached to *A. palmata* skeletons have more living tissue on their branch surfaces (mean=62% versus 51%). Fragments attached to coral skeletons also had lower levels of recent mortality (0.3%) and a lower prevalence of disease and corallivore predation, although both groups have a similar number and size of new branches. The most significant ongoing sources of mortality include predation by corralivores (8%), overgrowth by sponges in the genus *Cliona* (6%), and disease (6%). In addition to the substantial loss of restored fragments, this reef has been impacted by a severe outbreak of WBD that has persisted since 2001 and has eliminated over 95% of coral colonies that were not part of restoration efforts.

In the most recent major ship grounding in Puerto Rico, the M/T *Margara*, a 228 m tanker, ran aground on the reefs off of Guayanilla, Puerto Rico on April 27, 2006. The damage was extensive and estimated to have impacted up to 8,500 m$^2$ of reef. The grounding occurred at approximately 10.5 m depth on a bank type coral reef near the shelf edge that had significant live cover of corals and gorgonians. Emergency Restoration activities were conducted to facilitate the recovery of the natural resources by reattaching the remaining viable corals, stabilizing rubble berms and removing antifouling paint. Thousands of scleractinian corals and gorgonians were reattached to available substrate with hydraulic cement. The ER was a cooperative effort between the Responsible Party (represented by Continental Shelf Associates, Inc.) and the co-trustees, Puerto Rico DNER and NOAA. Damage assessment activities involved mapping impacted reef areas as well as a preliminary characterization of the surrounding reef community to establish a baseline of conditions in the area. Spur and groove coral reef habitats, like the area impacted by the M/V *Margara*, have complex topography and high species diversity compared with hard ground coral reef communities of low topographic complexity, where flat limestone pavements are colonized by crustose coralline algae, gorgonians and isolated coral colonies. This site will be monitored over time to determine the effectiveness of restoration activities and track any recovery that occurs.

In addition to groundings, shipping is often responsible for the release of petroleum products into the environment. NOAA ResponseLink data for November 2007 through January 2008 indicate that five spills of petroleum products from tug boats, tankers, and cargo vessels were reported to the National Response Center. The events occurred in San Juan, Ponce, and Yabucoa. While these areas are active harbors, reef resources are located in close proximity. In addition to these small reported spills, a large spill occurred in Guánica in August 2007. This spill went unreported and resulted in damage to mangrove forests, beaches, and coral cays from Guánica to Parguera along the southwest coast of Puerto Rico. Spill response also resulted in damage to shallow seagrass beds and mangrove forests during site access. The response took approximately one month and some areas, such as interior mangrove forests, could not be thoroughly cleaned. The U.S. Coast Guard (USCG) has identified the party responsible but the Oil Pollution Control Act allows compensation and restoration only for damages directly related to the spill. Therefore, there are no scientific investigations ongoing or planned in order to characterize the environmental impacts of this large magnitude spill.

The number of recreational vessels and personal watercrafts has been continuously increasing since 1993 (Figure 3.21). The DNER's Office of the Commissioner of Navigation keeps records of the USCG vessels larger than 16 feet. USCG boating statistics show that there were between 7 and 18 boating accidents reported in Puerto Rico between 2001 and 2005 to which the USCG responded (http://www.uscgboating.org/). However, no groundings or striking of submerged objects were reported.

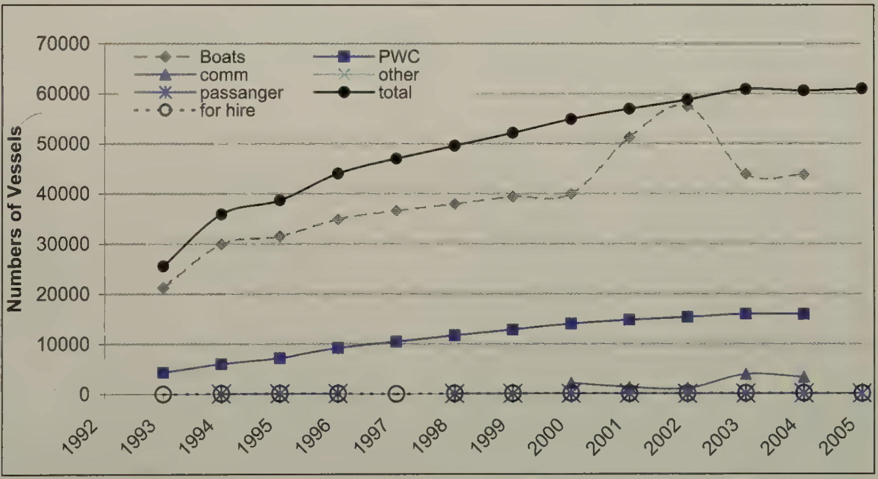


*Figure 3.21. USGS registered vessels in Puerto Rico from 1993 to 2005. Source: Office of the Commissioner of Navigation, Puerto Rico DNER.*

## Marine Debris

Marine debris has not been reported to be a significant problem affecting Puertorrican reefs.

## Aquatic Invasive Species

No updated information on this topic was provided.

## Security Training Activities

The islands of Vieques, Culebra and Desecheo served as training ranges for the U.S. Navy since the 1940s. Military activities ceased in 2001 on the western end of Vieques, and in 2003 on the eastern half of the island. In 2005, the EPA placed the former Navy areas on the National Priorities List (or Superfund). On the western side of the island, the Navy is identifying contaminated areas and performing cleanup of some of the sites. In the Live Impact Area, where cleanup efforts are more intensive due to the possible presence of unexploded live ordnance, the Navy has cleared several beaches and trails. The FWS, the agency now responsible for the management of the lands of eastern Vieques, has made some of the areas accessible to the public but most of eastern Vieques is still closed to the public as cleanup efforts continue. Because cleanup efforts include blow in place of unexploded ordnance, the Navy has agreed to restore some mangrove forests and coastal lagoons impacted by past military activities, as well as during the cleanup effort. Although no cleanup efforts have begun in the water, the Navy anticipates starting cleanup of unexploded ordnance in the water by 2010. A recent study (GMI, 2005) found that reefs in former military areas are in similar condition to the civilian areas, although the two sites with the poorest condition were located in the military target area. Although the extent of damage is not thoroughly established, recent efforts have highlighted the areas of greatest concern and estimated the amount of reef habitat that is potentially impacted by ordnance (GMI, 2003). NOAA's CCMA-BB recently conducted field surveys to characterize fish, benthic communities, marine debris, contaminants, and water column nutrients in coral reef ecosystems island-wide. The results and interpretation of this work will be provided in the next reporting effort. The Navy and NOAA have partnered to complete submarine mapping of potential areas of concern where unexploded ordnance may be present using different types of sonar. The results of these studies will help focus cleanup efforts. In addition, the results of these surveys have been used to determine where to install warning buoys notifying mariners of the danger of navigating and, in particular, weighing anchor in certain bays. NOAA is also conducting an artificial reef study to determine the form and composition of structures that are most successful in enabling coral recruitment and coral transplant survival. The results of this study will be used to guide mitigation planning as part of future underwater cleanup efforts.

In Culebra and its surrounding island and cays, the U.S. Army Corps of Engineers (COE) is responsible for cleanup efforts due to Culebra's classification as a Formerly Used Defense Site. This is also true for Desecheo Island due to the length of time since active military activities took place. COE has completed site inspections for Desecheo Island and is in the planning stages for determining the level of cleanup necessary in coordination with the FWS, as the agency responsible for management of Desecheo Island, which is a National Wildlife Refuge. The site inspection revealed that, in addition to possible ordnance on land, the area on the west of the island that was used as a target contains potential items of concern in areas of coral reefs. No decisions have been made to date regarding cleanup of these items. In terms of Culebra, efforts are already underway to clean some of the larger cays where sea bird and sea turtle nesting are not a concern. COE will also begin cleanup of beaches around Culebrita Island, as well as Flamenco beach. COE also completed a test of one of the sonar devices employed by the Navy to do underwater mapping of the coast of Culebra in the area of Canal Luis Peña Natural Reserve. If the results of the study reveal areas of potential unexploded ordnance, COE will proceed with the development of a plan for cleanup of these areas. To date, the potential impacts of ongoing cleanup efforts around Culebra on the coral reef ecosystem are related to the potential for accidental groundings during access of offshore islands and cays and blow in place of large bombs on cays of less than 0.5 acre, which could result in the elimination of the cay. COE has not been responsive to concerns related to potential impacts of cleanup on marine resources at this time. Therefore, FWS as the agency responsible for management of most of the offshore islands and cays as part of the Culebra Wildlife Refuge, may deny access to the Refuge.

The transfer of lands that were formerly part of Naval Station Roosevelt Roads also includes cleanup efforts. Piñeros and Cabeza de Perro Islands, formerly part of the base, were used to conduct training activities for Navy SEALs, as well as firing range practice, underwater demolitions, and other military training activities. The Navy, as part of cleanup efforts and a possible plan to transfer these two islands to DNER to become a Natural Reserve, investigated the lands and waters around these islands to determine potential hazards related to unexploded ordnance. A significant number of potential hazards were identified during underwater mapping of four sites around the islands. The Navy is now drafting a work plan for intrusive exploration of these sites and blow in place of items that prove to be unexploded ordnance. Because the areas are located in benthic habitats such as coral reefs and seagrass beds, cleanup activities are likely to result in impacts to marine resources. For this reason, the Navy is also working on potential measures to minimize impacts, as well as compensatory measures to address unavoidable impacts to seagrass beds and coral reefs.

### Offshore Oil and Gas Exploration

There are currently no offshore oil and gas exploration activities occurring in Puerto Rico.

## CORAL REEF ECOSYSTEMS—DATA-GATHERING ACTIVITIES AND RESOURCE CONDITION

The Department of Marine Sciences (DMS) from the University of Puerto Rico, Mayaguez Campus (UPRM) plays a leading role in scientific research related to coral reefs, associated reef communities and the physical characteristics and processes affecting reef systems. Data from these studies are often published in scientific journals and books or are available as theses or dissertations in UPRM's DMS Library (http://www.uprm.edu/library). The DMS also serves as the administrative office and operations center for the recently created Caribbean Coral Reef Institute (CCRI), which provides funding for coral reef related research in Puerto Rico and the Caribbean. CCRI has sponsored 12 projects since 2004, six of which have involved data collection, including annual monitoring of corals, diseases, macroinvertebrates, fishes at Culebra Island, Fajardo, Cabo Rojo, Mayaguez and Guánica.

The Coral Reef Ecosystem Studies (CRES) program at the DMS-UPRM has conducted routine sampling of coral reefs in La Parguera. Fixed transects are located on three inshore, three mid-shelf and two shelf edge locations, with three depths sampled at each location and three replicate transects at each depth. Quantitative sampling has been conducted since 2003 for corals (including recruits and coral diseases), algae, gorgonians, and fishes. Frequency of sampling varies depending on taxa, being lower for corals and gorgonians and higher for algae, fishes and coral recruits and diseases. Water quality has been monitored continuously at inshore, mid-shelf and shelf edge locations- temperature, salinity, turbidity, pH, photosynthetically active radiation (PAR)- with more detailed short-term measurements occurring at 14 locations from the shoreline to the shelf edge (temperature, salinity, turbidity, pH, PAR, Chlorophyll a, DCOM). At these latter sites sediment samples have been analyzed for stable isotopes. Additional sediment trap samples have been collected at all fixed transect sites at bimonthly intervals. All CRES field data collections ended in the spring of 2007. Table 3.4 summarizes data-gathering activities by ongoing coral reef monitoring programs in Puerto Rico and Figure 3.22 shows the distribution of monitoring sites.

*Table 3.4. Data sets selected to describe the current condition and status of coral reef ecosystems in Puerto Rico for the period 2004-2007. Source: S. Williams and J. García-Sais, unpub. data.*

| ECOSYSTEM COMPONENT | DATA SET | SOURCE AGENCY/ ORGANIZATION | PROGRAM INFORMATION |
|---|---|---|---|
| **Water Quality** | Coral Reef Early Warning System | NOAA Coral Health and Monitoring Program | CREWS Station, La Parguera |
| | 301-h Program | PRASA-CSA/CH2MHill | Submarine Outfalls |
| **Benthic Habitats** | Puerto Rico Coral Reef Monitoring Program (National Coral Reef Ecosystem Monitoring Program) | PRDNER, NOAA | Baseline characterization and monitoring of reef systems in Natural Reserves |
| | Media Luna Reef, La Parguera, PR | Caribbean Coastal Marine Productivity (CARICOMP) | CARICOMP Data Management Centre, Kingston Jamaica |
| | CRES | NOAA/CSCOR | http://ccma.nos.noaa.gov/ecosystems/coralreef/cres.html |
| | 301-h Program | PRASA-CSA/CH2MHill | Submarine Outfalls |
| | Coral Reef Monitoring Program | NOAA CCMA-BB | http://ccma.nos.noaa.gov/ecosystems/coralreef/cres.html |
| **Associated Biological Communities** | Reef Fish Monitoring Program (National Coral Reef Ecosystem Monitoring Program) | PRDNER, NOAA | Baseline characterization and monitoring of reef systems in Natural Reserves |
| | Coral Reef Monitoring Program | NOAA CCMA-BB | http://ccma.nos.noaa.gov/ecosystems/coralreef/cres.html |

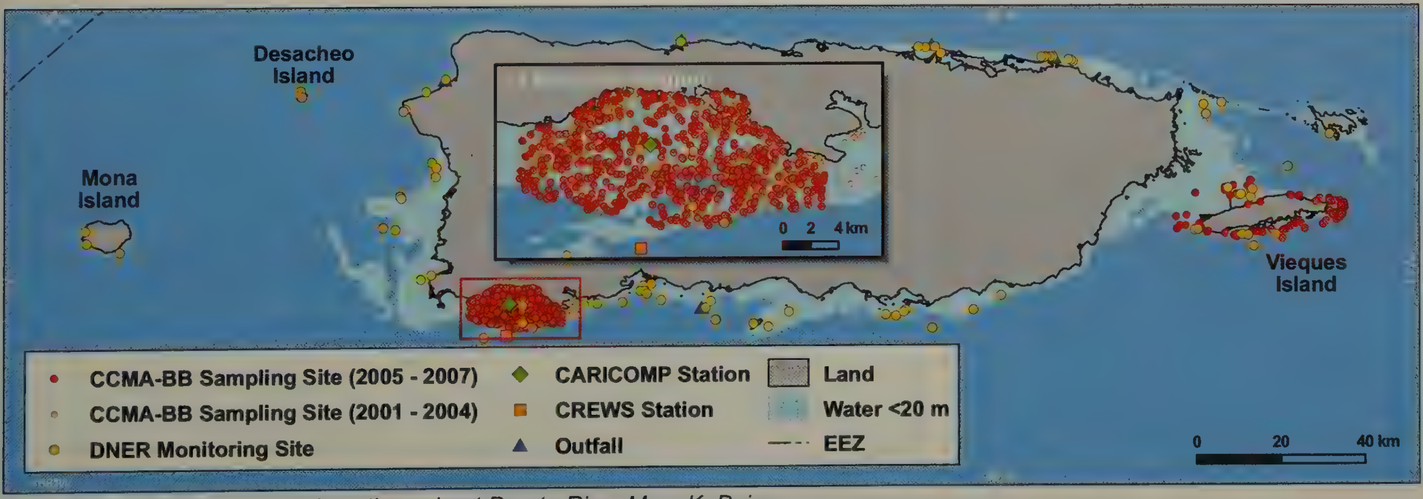


*Figure 3.22. Monitoring locations throughout Puerto Rico. Map: K. Buja.*

## WATER QUALITY AND OCEANOGRAPHIC CONDITIONS

### *Coral Reef Early Warning System (CREWS) Station*

NOAA's Coral Health and Monitoring Program has a Coral Reef Early Warning System (CREWS) Station that was installed at Media Luna Reef (17°52.326'N; 067°03.128'W) within the La Parguera Marine Reserve, Puerto Rico. The instruments and electrical infrastructure were installed in December, 2005, and the station began transmitting on January 15, 2006. Sensors provide measurements of wind speeds and gusts, barometric pressure, relative humidity, precipitation, photosynthetically available radiation (PAR, above and below water), ultraviolet radiation (UV 305, 330, 380 nm, above and below water), state of tide, sea temperature, salinity, and pulse amplitude modulating fluorometry on up to four species of coral. Validation runs and complete cleaning of the sensors and structure are performed on a continuous monthly basis. The station also serves as a navigational light between Cabo Rojo and Ponce, and an entrance channel marker to the reserve and general embayment area. Roy Armstrong and Francisco Pagan of UPR/DMS are the local contacts. To check archives and latest up-to-date information, visit the NOAA/CREWS Web site at http://ecoforecast.coral.noaa.gov/.

### *Puerto Rico Aqueduct and Sewer Authority 301-h Program*

PRASA operates a series of RWWTP that discharge primary treated effluents to the ocean via submarine outfalls. Discharges from PRASA facilities are regulated by a National Pollutant Discharge Elimination System permit from the EPA, Region II. Section 301(h) of the Clean Water Act and its implementing regulations require that a waiver recipient develop and implement a comprehensive marine monitoring program to determine whether discharges from the subject primary plant adversely affect the marine environment. The 301(h) program was originally designed to be carried out on a quarterly basis, but is at present performed semiannually at most plants. The 301(h) monitoring program elements include: influent and effluent water quality (150 parameters); receiving water quality (152 parameters); sediment quality; benthic (infaunal) invertebrate communities; fish and epibenthic invertebrate communities; and coral community assessment. The typical sampling station design includes one reference (control) station, one up-current and one down-current far field stations, one station at each end of the outfall structures, and at the boil whenever evident. Reports are prepared for PRASA by CSA Architects and Engineers/CH2MHILL/CSA Group, and submitted to the EPA Region II, Division of Environmental Planning and Protection, with copies to the Environmental Quality Board of Puerto Rico.

Table 3.5 presents data from a selected group of water quality parameters measured during the November 2005 monitoring survey in the vicinity of the Aguadilla RWWTP submarine outfall. Note that all dissolved nutrient concentrations and bacteriological analyses were below the detection limits established to protect human health or between the reporting limit and the detection limit during this survey. This data shows that coastal waters in the vicinity of the Aguadilla RWWTP submarine outfall tend to retain their oligotrophic character despite the influence of the effluent discharge. Other plants, such as the Ponce RWWTP have had problems that have resulted in unauthorized discharges to marine waters.

*Table 3.5. Water quality of surface waters near PRASA-RWWTP in Aguadilla, PR during November, 2005. Source: CH2MHILL, 2006.*

| PARAMETER | UNITS | STATIONS | | | | |
|---|---|---|---|---|---|---|
| | | BOIL | A-1 | A-3 | A-4 | A-7 |
| Temperature | °C | 26.15 | 26.61 | 26.32 | 26.25 | 26.20 |
| Salinity | ssu | 36.41 | 36.65 | 35.54 | 36.51 | 35.56 |
| Dissolved Oxygen | mg/l | 5.95 | 6.12 | 6.21 | 6.14 | 6.07 |
| $O_2$ Saturation | (%) | 91.5 | 95.0 | 95.2 | 94.6 | 93.1 |
| pH | su | 8.02 | 8.05 | 7.98 | 8.04 | 7.97 |
| Total Suspended Solids | mg/l | 5U | 5U | 5U | 5U | 5U |
| Turbidity | NTU | 0.22J | 0.43J | 0.2J | 0.15J | 0.24J |
| Total Phosphorus | mg/l | NA | 0.01U | 0.01U | 0.01U | 0.01U |
| Ammonia as N | mg/l | 0.15U | 0.03UJ | 0.03UJ | 0.03UJ | 0.03UJ |
| Total Kjeldahl Nitrogen | mg/l | 1.6J | 0.13J | 0.21 | 0.2J | 0.20 |
| $N0_3$/$N0_2$-N | mg/l | 0.03J | 0.03J | 0.03J | 0.03J | 0.03J |
| Chlorophyll-a | $mg/m^3$ | 0.19 | 0.11 | 0.10U | 0.32J | 0.31J |
| Total Coliforms | col/100ml | 99 | 10U | 10U | 10U | 10U |
| Fecal Coliforms | col/100ml | 2U | 2U | 2U | 2U | 2U |

U: below detection limit
J: Estimated value; compounds detected at concentrations between the reporting limit and the detection limit.

## BENTHIC HABITATS

### National Coral Reef Ecosystem Monitoring Program (NCREMP): Puerto Rico Habitat Monitoring

The Puerto Rico Coral Reef Monitoring Program (PRCREMP), which is sponsored by NOAA and administered by the DNER, began in 1999; the program is now fully implemented and is achieving its goals in collaboration with federal and local governmental agencies and marine scientists from research institutions. The main objectives of the program are to map the spatial distribution of coral reefs, produce a baseline characterization of priority reef sites and establish a monitoring program for high-priority reefs. The monitoring program provides information needed for effective resource management and public awareness, while contributing to a scientific database for long-term analysis of the coral reefs in natural reserves of Puerto Rico. The purpose and priorities of the PRCREMP were initially presented by the DNER to NOAA's U.S. Island Coral Reef Initiative in 1997.

DNER identified the natural reserves of Mayaguez Bay, Desecheo Island, Mona Island, Rincón, Guánica, Caja de Muerto Island, Ponce Bay, La Parguera, Cordillera de Fajardo, and the islands of Culebra and Vieques as high-priority monitoring sites. Baseline characterizations for these reef systems were prepared by García-Sais et al. (2001a, 2001b, 2001c, 2001d, 2004, 2005c, 2006). The baseline characterization and monitoring for the Culebra Marine Reserve was prepared by Hernández-Delgado (2003). This report includes annual monitoring trends from 12 stations at six reefs surveyed as part of PRCREMP. These included reefs at Isla Desecheo, Rincon, Mayaguéz, Guánica, Isla Caja de Muerto and Ponce. At each reef, quantitative measurements of the percent substrate cover by sessile-benthic categories and visual surveys of species richness and abundance of fishes and motile megabenthic invertebrates were performed along five permanent transects per station. Table 3.6 provides sites for which quantitative baseline characterizations are available, along with geographic references and depths. During fiscal year 2008, three additional reefs from Mona Island will be included in the monitoring program.

*Table 3.6. Geographic coordinates and depths of coral reefs surveyed as part of the Puerto Rico Coral Reef Monitoring Program. Source: García-Sais et al., 2005c.*

| REEF SITE | DEPTH (m) | LATITUDE | LONGITUDE |
|---|---|---|---|
| **Rincón** | | | |
| Rincón elkhorn reef | 3 | 18° 21.023' N | 067° 15.959' W |
| Rincón mid shelf | 10 | 18° 20.832' N | 067° 16.206' W |
| Rincón shelf edge | 20 | 18° 20.790' N | 067° 16.248' W |
| **Isla Desecheo** | | | |
| Desecheo inner shelf - Puerto Botes | 15 | 18° 22.920' N | 067° 29.300' W |
| Desecheo mid shelf - Puerto Botes | 20 | 18°22.900' N | 067° 29.315' W |
| Desecheo shelf edge - Puerto Canoas | 30 | 18°22.706' N | 067° 29.199' W |
| **Mayaguez** | | | |
| Tourmaline 10 m | 10 | 18° 09.788' N | 067° 16.424' W |
| Tourmaline 20 m | 20 | 18° 09.910' N | 067° 16.512' W |
| Tourmaline 30 m | 30 | 18° 09.985' N | 067° 16.581' W |
| **Ponce** | | | |
| West Reef of Caja de Muerto | 7.6 | 17° 53.701' N | 066° 31.703' W |
| Derrumbadero | 20 | 17° 54.2371' N | 066°36.5161'W |
| **Guánica** | | | |
| Cayo Coral | 7.6 | 17° 56.173' N | 066° 53.303' W |

*Methods*

At each site, reef substrate cover by sessile-benthic categories (including corals) was monitored using the Caribbean Coastal Marine Productivity (CARICOMP, 1996) chain link method. Five, 10 m-long permanent transects were surveyed per reef. Belt-transects (5-10 m long x 3 m wide) were surveyed for determinations of taxonomic composition and abundance of fishes and motile megabenthic invertebrates. Monitoring surveys were conducted annually at each reef during a period that extended from late spring through summer (May–August).

*Results and Discussion*

The sessile-benthic community at the reef systems of Puerto Botes and Puerto Canoas (Isla Desecheo), Tourmaline Reef (Mayaguez), Cayo Coral (Guánica), West Reef (Caja de Muerto–Ponce) and Derrumbadero Reef (Ponce) presented statistically significant reductions of live coral cover (Figure 3.23). The most pronounced declines of live coral cover were observed between the 2005 and the 2006 monitoring surveys. Reductions of live coral cover up to 59% were measured at Derrumbadero Reef between the 2005 and 2006 surveys. A decline of 56% was measured from a depth of 20 m at Puerto Canoas Reef at Desecheo Island. West Reef at Caja de Muerto Island declined 42% over the same period. In all cases, the decline of (total) live coral cover at the community level was driven by mortality of *Montastraea annularis* complex, a highly dominant species in terms of reef substrate cover and the principal reef-building species in Puerto Rico and the Caribbean (Figure 3.23). A proportional increase of cover by turf algae was typically observed (Figure 3.23).

The Tres Palmas Reef system in Rincon did not exhibit any major structural changes, nor statistically significant variations of percent substrate cover by live corals at any of the three depths surveyed between the initial 2004 baseline characterization and subsequent 2005 and 2006 monitoring surveys. The fringing shoreline reef at Tres Palmas is largely an elkhorn coral (*Acropora palmata*) biotope, and is dominated by encrusting great star coral (*Montastraea cavernosa*) at the patch reef formations of the mid-shelf (10 m depth). The shelf-edge reef at Tres Palmas was studied at a depth of 20

m. It is dominated by *Montastraea annularis* complex, but reductions of live coral cover at the 20 m depth were small and not statistically significant (ANOVA; p>0.05).

Tourmaline Reef in Mayaguez Bay exhibited significant declines of cover of *Montastraea annularis* complex at 10 and 20 meter depths, but differences of substrate cover by sessile-benthic components were not statistically significant at the 30 meter depth, which was the deepest station examined. The decline of live coral cover from the 30 m depth station at Puerto Canoas Reef, Isla Desecheo was less pronounced than at shallower stations examined (e.g., 20 and 10 m), but it was still substantial (ca. 23 %), statistically significant, and found consistently throughout all transects.

The sharp decline of live coral cover at many of the reefs included in this monitoring program was associated with a severe massive regional coral bleaching event that affected the USVI and Puerto Rico during August through October, 2005 (García-Sais et al., 2006). The massive bleaching of corals coincided with an extended period of elevated sea SSTs. As much as 14 DHW, an indicator of thermal stress acting upon shallow reef communities, were measured from daily temperature records produced by a NOAA/ National Environmental Satellite, Data, and Information Services satellite infrared radiometer. The exposure of reef systems to such high SSTs was influenced by the presence of a warm anticyclonic eddy passing along the south (Caribbean) coasts of Puerto Rico and the USVI (see the Climate Change and Coral Bleaching Section of this chapter). During 2006 coral monitoring surveys, approximately six to nine months after the bleaching event, a relatively high proportion of live corals, particularly *Montastraea annularis* complex were observed to still retain partially bleached conditions. The potential recuperation of these (partially bleached) corals is uncertain at this point. Lingering effects of the October 2005 bleaching event were evaluated during the 2007 coral monitoring surveys and will be presented in the next report.

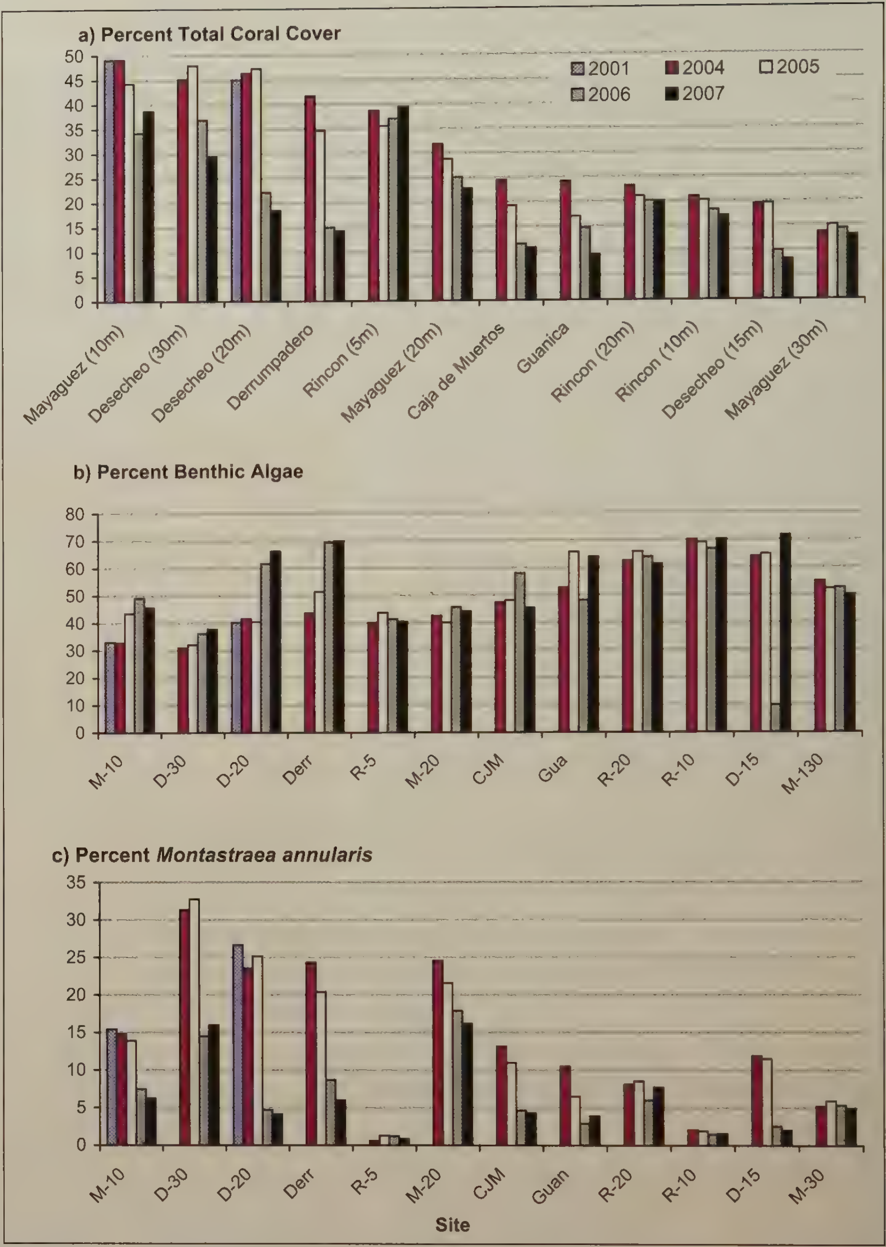


*Figure 3.23. Annual trends of (a) percent total coral cover, (b) percent cover by benthic algae, and (c) percent cover by* Montastraea annularis *from coral reefs monitored as part of the U. S. National Coral Reef Monitoring Program in Puerto Rico. García-Sais et al., 2007.*

Fish populations presented a general trend of declining abundance and species richness within belt-transects. Reductions of fish abundance were statistically significant in seven out of the 12 reef stations surveyed. These included Tourmarine Reef (Mayaguez) at 20 m; Puerto Botes Reef (Isla Desecheo) at 15 m; Tres Palmas Reef (Rincon) at 10 and 20 m; Derrumbadero Reef (Ponce) at 20 m and West Reef (Isla Caja de Muerto) at 8 m. Likewise, statistically significant reductions of fish species richness were observed at Tourmarine Reef (Mayaguez) at 20 m; Puerto Botes Reef (Isla Desecheo) at 15 m; Tres Palmas Reef (Rincon) at 10 m and West Reef (Isla Caja de Muerto) at 8 m. Variations between surveys were mostly associated with reductions of abundance by numerically dominant populations that exhibit highly aggregated distributions in the immediate vicinity of live coral heads, such as the masked goby (*Coryphopterus personatus*) and the blue chromis (*Chromis cyanea*). It is uncertain at this point if such reductions of abundance by reef fishes closely associated with coral habitats are related to the massive coral mortality exhibited by reef systems in the monitoring program. Although in low abundance, large demersal (top predator) fishes were detected during active search census surveys in several reefs. These include yellowfin, tiger, goliath and Nassau groupers (*Mycteroperca venenosa*, *M. tigris*, *Epinephelus itajara* and *E. striatus*), and the Cubera, dog and mutton snappers (*Lutjanus cyanopterus*, *L. jocu* and *L. analis*).

## Caribbean Coral Reef Institute

CCRI is a cooperative program between the UPRM and NOAA, and sponsors management-driven research through a request-for-proposal and peer review process. CCRI-sponsored research funds work related to mapping and resource assessment, anthropological and biological aspects of Marine Protected Area (MPA) design and implementation, applied coral reef biology and ecology and technology development.

### Spawning Aggregations

Many commercially important fishes form spawning aggregations that are highly predictable in space and time, a behavior that makes them highly vulnerable to fishing. Many of these aggregations have been overfished, some to the point of collapse. If management/conservation intervention occurs before complete collapse, they have the potential to recover. Edgardo Ojeda led an investigation to identify potential spawning aggregations using traditional ecological knowledge. Interview-based surveys were conducted to identify additional potential spawning aggregation sites throughout Puerto Rico. The survey targeted 50 key stakeholders consisting of commercial and sport fishers using skin-diving who were identified as knowledgeable, long-term users of local fisheries resources.

Using charts and Geographic Information System (GIS) analysis, information was obtained about 27 past and 93 present "potential" (non-overlapping) spawning aggregation sites, spawning times, changes in species composition in time and space, spawning-site fidelity, as well as 71 sites supporting multiple spawning species. The information included a total of 59 species, primarily snappers (12), groupers (11), jacks (seven) and mackerels and other fish of the family Scombridae (five). Table 3.7 shows the number of potential extant and former spawning aggregations for shallow water snappers, groupers and the hogfish. The percentage of potentially extant aggregations shows a general decline with increasing size, showing that larger, more commercially desirable species have been most severely impacted. It is assumed that the numbers of collapsed aggregations are underestimated. The status of rare species, e.g., Cubera snapper (*Lutjanus cyanopterus*) and black grouper (*Mycteroperca bonaci*) is poorly understood.

*Table 3.7. Potential number of extant and collapsed spawning aggregations of shallow water snappers, groupers and the hogfish as identified by knowledgeable stakeholders in Puerto Rico, along with an index of maximum length (mm). Source: R. Appeldoorn, modified from Ojeda-Serrano et al., 2007; fish lengths from http:/www.fishbase.org.*

| | EXTANT | COLLAPSED | PERCENT EXTANT | LENGTH |
|---|---|---|---|---|
| **GROUPERS** | | | | |
| *Cephalopholis cruentata* | 4 | 0 | 100 | 415 |
| *Epinephelus guttatus* | 37 | 13 | 74 | 471 |
| *E. adscensionis* | 10 | 3 | 77 | 499 |
| *Mycteroperca interstitialis* | 3 | 0 | 100 | 690 |
| *Cephalopholis fulva* | 13 | 0 | 100 | 699 |
| *M. tigris* | 15 | 1 | 94 | 740 |
| *E. morio* | 8 | 1 | 89 | 854 |
| *M. venenosa* | 25 | 4 | 86 | 860 |
| *E. striatus* | 14 | 5 | 74 | 938 |
| *M. bonaci* | 7 | 0 | 100 | 1352 |
| *E. itajara* | 3 | 4 | 43 | 2394 |
| *Hogfish* | -- | -- | -- | -- |
| *Lachnolaimus maximus* | 6 | 3 | 67 | 913 |
| **SNAPPERS** | | | | |
| *Lutjanus apodus* | 14 | 0 | 100 | 570 |
| *L. mahogani* | 12 | 2 | 86 | 618 |
| *L. griseus* | 7 | 0 | 100 | 722 |
| *L. jocu* | 7 | 0 | 100 | 854 |
| *L. analis* | 25 | 3 | 89 | 939 |
| *L. cyanopterus* | 6 | 0 | 100 | 1400 |

### Assessment of Ornamental Fishery Stocks

Attempts at regulation of the ornamental fishery in Puerto Rico were hindered by an information gap that led to worst-case assumptions of impact and a closure of the fishery, setting the stage for threatening personal confrontations and lawsuits. One particular scenario led to *de facto* resource management by judicial order. Following the judicial action, an assessment of wild populations relative to harvest levels was undertaken by Steve LeGore. Visual censuses stratified by habitat were conducted in areas of western Puerto Rico where most of the fishing activity is located. Results were used to calculate a first-order estimate of the total populations of each of 16 species of fish and 21 species of invertebrates.

### *Results and Discussion*

Comparisons of aggregated fish population estimates against annualized harvest data derived from export records from the 1998-2000 year period (Table 3.8) show that this finfish fishery represents a very small percentage of the estimated populations. Only two species had exports that represented more than 1% of the estimated populations, namely the rock beauty (*Holacanthus tricolor)* with 1.56%, and the French angelfish (*Pomacanthus paru)* with 1.16%.

*Table 3.8. Fish and invertebrate population estimates and harvest for two areas of western Puerto Rico. Source: LeGore, 2006.*

| **Common Name: Fishes** | **AGGREGATE POP. EST.** | **HARVEST/ANNUM[1]** | **PERCENT HARVESTED** |
|---|---|---|---|
| Royal gramma | 2,776,826 | 15,024 | 0.54% [2] |
| Blue chromis | 12,329,818 | 1,419 | 0.01% |
| Bluehead wrasse | 37,852,014 | 844 | <0.01% |
| Red lip blenny | 176,307 | 1,366 | 0.78% [2] |
| Blackbar soldier | 2,187,854 | 344 | 0.02% |
| Blue tang | 1,002,650 | 868 | 0.09% |
| Neon wrasse | 2,074,370 | 500 | 0.02% |
| Rock beauty | 81,014 | 1,263 | 1.56% [2] |
| Yellowhead jawfish | 1,001,130 | 3,388 | 0.34% |
| French angel | 44,274 | 513 | 1.16% [2] |
| Gray angel | 68,330 | 87 | 0.13% |
| Spanish hogfish | 122,607 | 716 | 0.58% [2] |
| Beaugregory | 1,578,978 | 56 | <0.01% |
| Sharpnose puffer | 1,045,101 | 160 | 0.02% |
| Yellowtail hamlet | 170,194 | 4 | <0.01% |
| Yellowtail damsel | 3,585,369 | 454 | 0.01% |
| **Common Name: Invertebrates** | **AGGREGATE POP. EST.** | **HARVEST/ANNUM[1]** | **PERCENT HARVESTED** |
| Blue legged hermit crab | 629,507,025 | 18,936 | <0.01% |
| Pink tip anemone | 1,067,422 | 17,518 | 1.64% [2] |
| Feather duster | 5,511,839 | 1,550 | 0.03% |
| Curly cue anemone | 5,167,892 | 1,300 | 0.03% [2] |
| Flame scallop | 12,414 | 1,341 | 0.80% |
| Sea mat | N/A | 1,594 | N/A |
| Sea cucumber | 39,817,333 | 1,200 | <0.01% |
| Emerald crab | 3,276,842 | 3,155 | 0.01% [2] |
| Red thorn starfish | 173,072 | 650 | 0.38% |
| Sunray anemone | 14,149 | 600 | 4.24% |
| Pincushion urchin | 11,213,888 | 600 | 0.01% |
| Carpet anemone | 1,947,691 | 554 | 0.03% [2] |
| Bahamas starfish | 346,195 | 300 | 0.09% |
| Shaving brush | 515,610,763 | 240 | <0.01% |
| Brittle starfish | 62,254,955 | 4,162 | 0.01% |
| Harlequin serpent star | 98,862,296 | 424 | <0.01% |
| Long spine urchin | 45,711 | 200 | 0.44% |
| Corky sea fingers | 29,291,774 | 190 | <0.01% |
| Fan halimeda | 200,831,013 | 150 | <0.01% |
| Red rock urchin | 143,452,102 | 150 | <0.01% |

*[1] = Annualized over 30-month period 1998-2000. [2] = Potentially overstated percent harvest.*

Similar results were obtained for invertebrates. Export of only three species represented more than 1% of the population estimates, namely the pink tip anemone, the flame scallop and the sunray anemone. In the cases of the pink tip anemone and the flame scallop, results are somewhat misleading because in both of these cases primary habitat was not sampled and their extant populations are probably underestimated, resulting in overstated harvest rates.

These population estimates are considered "minimum" estimates, in that there are at least as many individuals in the wild populations. Existing ornamental fisheries are currently considered small in terms of impact and number of collectors (20-25) and provide an excellent opportunity to implement rational management policies that assure the continued vigor of the wild populations while providing for sustainability of ornamental fishery income.

### Habitat Mapping of Western Puerto Rico

Puerto Rico's western insular shelf is a diverse mosaic of benthic habitats and supports known reef fish spawning aggregation sites, three of the six federal U.S. Caribbean MPA's and longstanding and intense fishing activities. However, much work needs to be done to better characterize this region. Unfortunately, due to prevalence of habitats in water depths <30 m and turbidity in the region, extensive areas of the western shelf were classified as unknown in the maps NOAA generated in 1998 based on aerial photographs of the region. Since publication of NOAA's map products, Jose Rivera has been using acoustic technology such as sidescan sonar to expand the extent and precision of benthic habitats in this area, and NOAA has targeted this area for deepwater multibeam sonar bathymetric surveys as described below.

Side scan sonar data was used to resolve benthic habitats, while a drop camera was used to ground-truth classification accuracy. From the imagery, GIS-based maps were developed with a minimum mapping unit of 8 m$^2$. Focus areas for this period covered nearshore locations off Añasco, Mayagüez, Guanajibo and Boquerón.

#### *Results and Discussion*

Four detailed habitat maps, including over 20 habitat types, were produced covering a total area of 6,975 ha. These benthic habitat maps have increased benthic knowledge of the western insular shelf. Of the total area mapped, 5,455 ha provide information for previously unidentified or unknown benthic habitats. The high resolution habitat maps generated through this work also provides information for ecosystem-based fishery management policies and for more precise inventories of the marine ecosystem present on the western shelf.

### NOAA's Benthic Habitat Mapping of Puerto Rico

CCMA-BB initiated benthic mapping activities to inventory the reef ecosystem and associated bottom types for Puerto Rico in 1998. Twenty-one distinct benthic habitat types within eight geomorphological zones were mapped directly into a GIS using visual interpretation of orthorectified aerial photographs. Benthic features covering over 1600 km$^2$ were mapped according to methods described in Kendall et al. (2001). Data revealed 49 km$^2$ of unconsolidated sediment, 721 km$^2$ of submerged vegetation, 73 km$^2$ of mangroves, and 756 km$^2$ of coral reef and colonized hardbottom (Figure 3.24). Maps and associated products are available at http://ccma.nos.noaa.gov/products/biogeography/benthic/welcome.html.

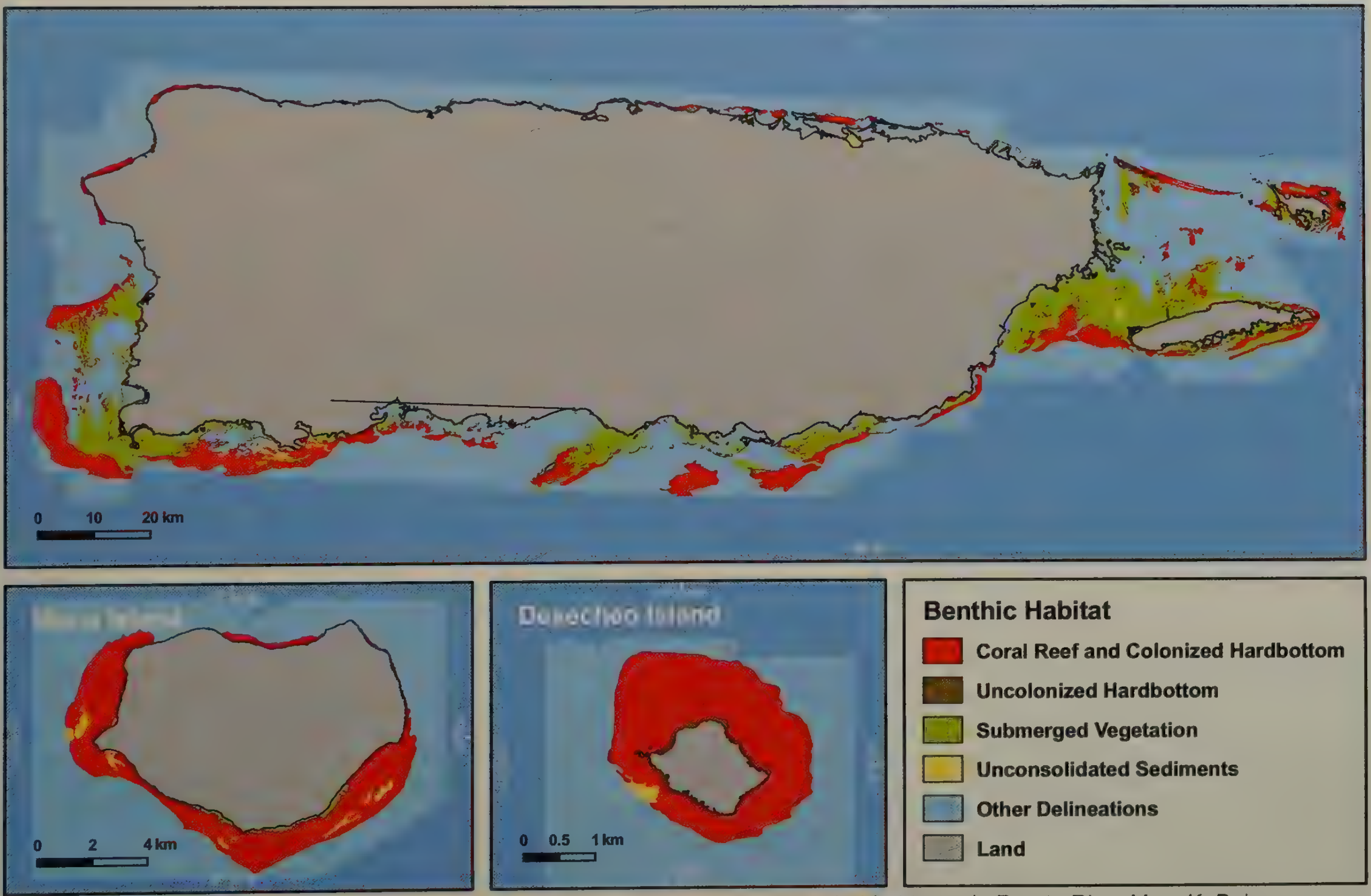


*Figure 3.24. Benthic habitat maps showing the distribution and extent of primary habitat types in Puerto Rico. Map: K. Buja.*

## *NOAA's Coral Reef Ecosystems Study*

Based at the UPRM, NOAA's Center for Sponsored Coastal Ocean Research initiated a CRES in 2002 that consisted of a five-year collaborative research program involving five universities, one non-governmental organization (NGO) and two federal agencies. The study addressed four major research focus areas: 1) relationships between watershed activities and coral reefs; 2) causes of ecological stress; 3) coral reef ecosystem integrity; and 4) evaluation and linkages of marine protected areas. Specific results relative to coral diseases and bleaching are reported elsewhere; selected results relative to resource condition are presented below.

### *Algal Population Dynamics*

On healthy coral reefs, macroscopic algae are relatively inconspicuous but relatively abundant, with high species richness. Long-term sampling has shown the benthic algal community to be highly dynamic as well. Figure 3.25 illustrates the changes in average algal cover observed at the edge of the insular shelf off La Parguera over a three-year period. The most conspicuously dominant algal species is *Lobophora variegata*. An increase in the cover of this species (to approximately 25%) since October 2004 is largely driving an increase in total algal cover, from 42.9% to 69.7%. Two large blooms of cyanobacteria (*Schizothrix* sp.) also occurred during this period. Despite over two decades of observation, cyanobacterial blooms were not observed at shelf edge locations until a few years ago. There are disturbing trends as the site illustrated is a coral dominated reef site that is being increasingly covered by algae. This steady increase in algal cover at offshore sites (in addition to presence of cyanobacterial blooms) may well indicate the development of an alternative state in these reefs.

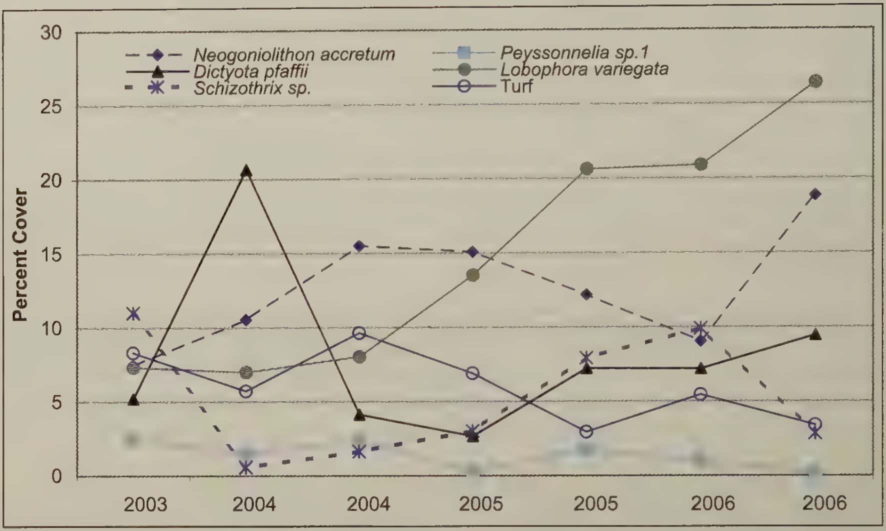


*Figure 3.25. Percent cover of principal benthic algal components from 2003 to 2006 at Weinberg, a site at the shelf edge off La Parguera, Puerto Rico. Source: D.L. Ballantine and H. Ruíz, unpub. data.*

### *Nutrient and Sediment Transport Pathways*

One of the basic premises of the CRES program was that the integrity of coral reef ecosystems depends upon low rates of transport of watershed-based materials to the marine environment. A secondary premise was that offshore transport rates result from interactions between geomorphological features, wind, wave and tidal patterns. These premises are supported by CRES results. Data from sediment traps, sediment cores, runoff studies, water quality and current meters indicate that flow in the La Parguera area can be divided into two components: inshore and offshore.

Local runoff from La Parguera watersheds is entrained near the shoreline and moves westward. During larger runoff events the outer extension of the sediment plume may reach only the middle emergent reefs (e.g., Cayo Enrique) and San Cristobal to the west. Thus, during normal conditions the outer emergent reefs and the outer shelf are protected from local runoff. Runoff from upstream of La Parguera comes from the east (e.g., Guanica, Guayanilla and Ponce). Wind driven circulation wraps around the eastern margin of La Parguera to flow along the reef margin and enter the basin inside the outermost emergent reefs before being transported out through cuts between the outer reefs. Thus, the outer reefs and shelf extending to the shelf edge are primarily influenced by upstream sources of nutrients, turbidity and sediments. The combined flow patterns essentially isolate the reefs from local runoff effects, with water borne nutrients and particulates channeled behind the inner reefs and kept within seagrass and mangrove areas.

Sediment cores form inshore sites do not show increased rates of sedimentation, but the dates associated with the cores do not extend beyond the period of active coastal development within La Parguera. Outer sediment cores show some evidence of increased sedimentation rates over time. This suggests that impacts from upstream development have been increasing overtime, which is supported by the observations of increased algal growth at the shelf edge.

### *Assessment of Reef Fisheries*

In developing models to provide management applications from the CRES program, researchers from the University of Miami tested a length-based stock assessment model using data from the commercial fisheries. The model compares actual mean lengths of populations to those calculated for a theoretical unfished population (Figure 3.26). While the parameters, and hence results, for individual species may vary, the results are robust across the suite of species to give a broad look at the reef fishery as a whole. The majority of species were found to be overfished, with some substantially overfished. The larger groupers that have not been overfished are rare or known to cause ciguatera poisoning in humans. Overall, this suggests that, despite evidence of a substantial decrease in fishing effort over the last 20 years, the reef fish fishery is still suffering from an excess of fishing pressure. These results support the more stringent regulations recently introduced by the Puerto Rico government and the CFMC.

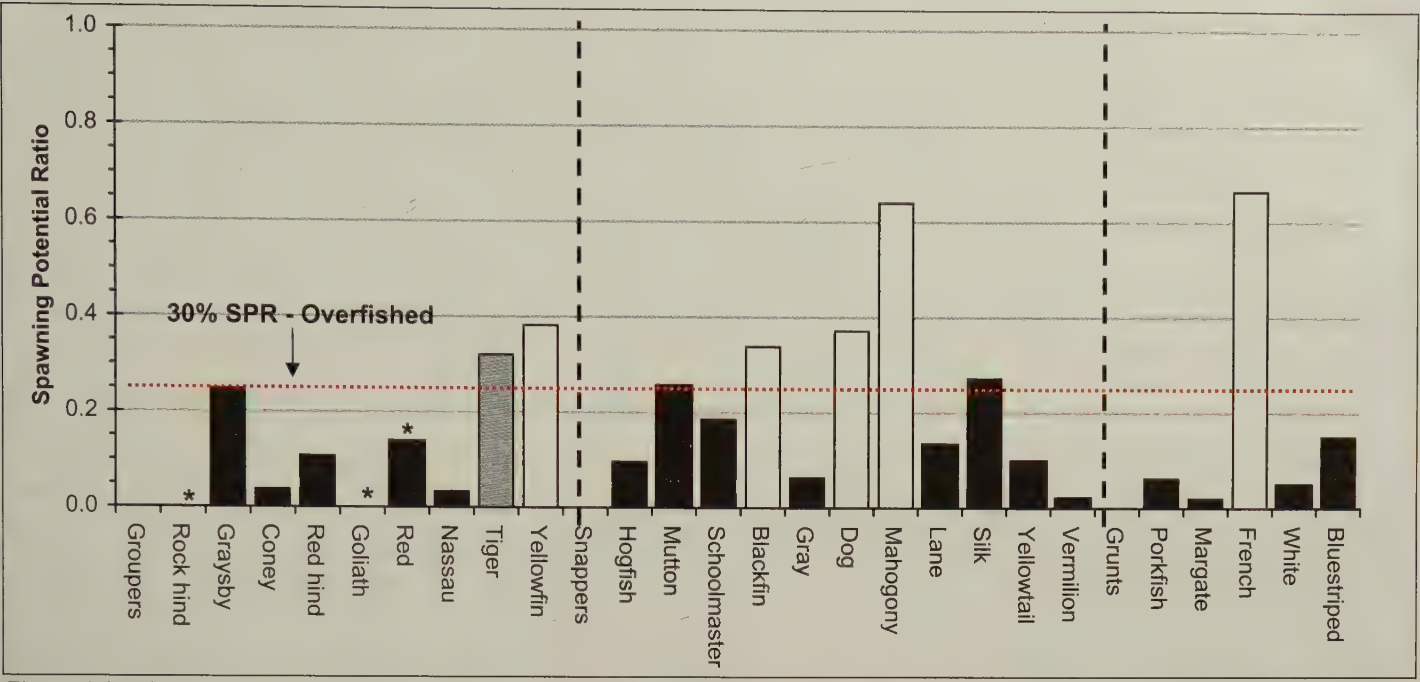


*Figure 3.26. Comparative spawning potential ratio (SPR) analysis for 25 exploited reef fish species from Puerto Rico between 2000-2002. Dark bars indicate overfished stocks, open bars indicate stocks that are above the 30% SPR standard and gray bars indicate that stocks are within 3% of the SPR standard. Asterisks (*) denote species with unreliable estimated rates of fishing mortality. Source: Ault et al., in review.*

## *Impacts of Water Quality on Reef Communities*

Sediment and nutrient inputs increase water turbidity, which limits light availability, reduces photosynthetic capacity, causes stress and in extreme cases suffocation or death among coral colonies. With support from the Puerto Rico DNER, Researchers from the UPR Department of Marine Sciences studied the relationship between water turbidity, measured as vertical attenuation of PAR (Kd), and coral and fish communities. The 35 study sites were located in southwest Puerto Rico, had a constant depth of 10 m, and spanned a range of water turbidity levels. At each site, fish and coral communities were characterized using visual census and benthic surveys, respectively. Vertical attenuation of PAR was measured several times over the year to include wet and dry seasonal effects.

### *Results and Discussion*

For sites along the southwest coast that displayed similar reef structure, coral cover (%) showed a strong correlation with light attenuation (Figure 3.27), which itself was strongly correlated to distance from shore. The fish community also varied with light attenuation, with fish density ($r^2$=0.322; Figure 3.27) and biomass ($r^2$=0.229) being positively related to water clarity. This effect was independent of the positive correlation of fish density ($r^2$=0.259) and species richness ($r^2$=0.382) to rugosity, or the positive correlation of species richness and percent live coral cover ($r^2$=0.267). Results indicate that deterioration in water quality due to increases in anthropogenic sources of nutrients and sediments will result in further degradation of reef communities. These results may also explain the strong correlation between reef health and distance from shore that was observed in several monitoring programs in Puerto Rico.

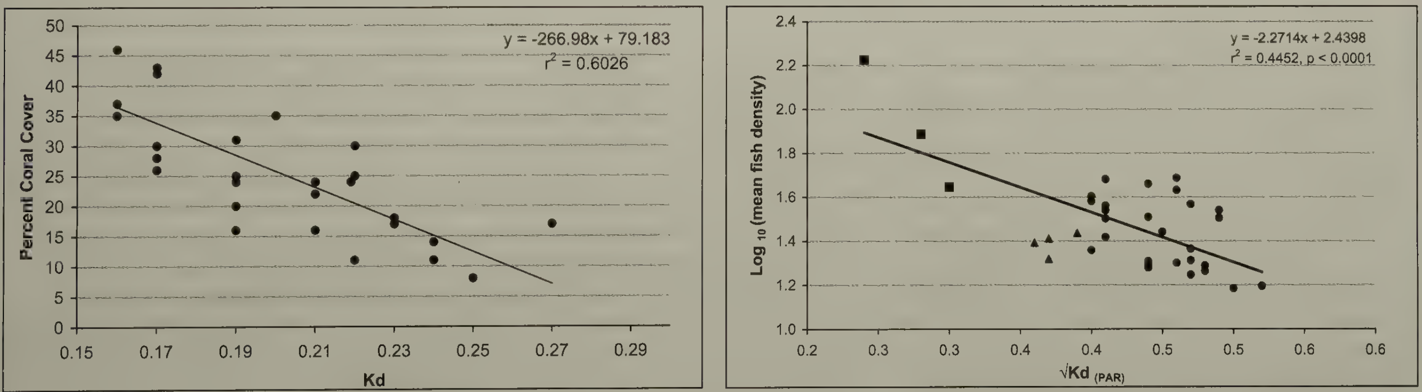


*Figure 3.27. Regression of the vertical attenuation coefficient of light and percent live coral cover (left) and mean fish density (right). Squares indicate Mona Island sites, triangles are hardbottom sites and circles indicate all other sites. Source: Bejarano-Rodriguez, I, 2006.*

## *NOAA's Coral Reef Ecosystem Monitoring Project in La Parguera*

The goals and objectives of CCMA-BB's Caribbean Coral Reef Ecosystem Monitoring Project are five fold: 1) to spatially characterize and monitor the distribution, abundance, and size of both reef fishes and macro-invertebrates (conch, lobster, *Diadema*); 2) to relate this information to *in situ* data collected on associated benthic composition parameters; 3) to use this information to establish the knowledge base necessary for enacting management decisions in a spatial setting; 4) to establish the efficacy of those management decisions; and 5) to work with the National Coral Reef Ecosystem Monitoring Program to develop data collection standards and easily implemented methodologies for transference to other agencies. In Puerto Rico, CCMA-BB's work focuses on coral reef ecosystems in the La Parguera region of southwestern Puerto Rico and monitors sites based on random sampling within habitat strata. Field missions have been conducted two or three times per year since 2001 and involve collection of data on fish, macro-invertebrates and benthic composition at approximately 90 monitoring sites. Data has been collected in collaboration with and extensively used by the University of Miami, UPR, Puerto Rico DNER, the CFMC, NOAA's National Marine Fisheries Service and others. Data collected by CCMA-BB can be accessed at http://www8.nos.noaa.gov/biogeo_public/query_main.aspx.

### *Methods*

Survey sites are selected using a stratified random sampling design that incorporates strata derived from CCMA-BB's nearshore benthic habitat maps (Kendall et al., 2001) to ensure comprehensive coverage of the study region. At each site, fish, macro-invertebrates, water quality and habitat information are quantified following standardized protocols that are available online at http://ccma.nos.noaa.gov/ecosystems/coralreef/reef_fish/protocols.html. CCMA-BB's field methodology consists of two complementary components. A 25 x 4 m belt transect is used to quantify fish species size and abundance at sites chosen through random stratified sampling. The second component involves taking detailed habitat measurements at five locations along the same belt transect. Fish data is then analyzed in conjunction with habitat information to identify spatial patterns in community structure.

### *Results and Discussion*

A total of 442 surveys were conducted on randomly selected coral reef and hardbottom sites from 2001-2006. Over the six-year sample period, turf algae accounted for the highest mean percent cover, followed by macroalgae, gorgonians, hard coral and sponges (Figure 3.28). Cover of turf algae exhibited wide temporal variation; in most years it ranged from 20-40% but exceeded 50% during two survey periods in 2002. Mean macroalgal cover generally ranged between 10-20% with a low of 2.6 ± 1.6% in May 2001 and a high of 37.8 ± 17.7% in January 2001. Crustose coralline algae comprised a smaller component of the algal community; mean cover was ≤3.5% in all years. Mean sponge cover ranged from 1.7 ± 0.4% to 4.5 ±0.8%; mean gorgonian cover ranged from 4.0 ± 0.7% to 9.6 ± 2.0%.

Mean ± SE live coral cover has ranged from a low of 4.2 ± 0.8% in August 2006 to >10% in 2001/2002. Mean fire coral (*Millepora* spp.) cover was less than 1% in all years. Live scleractinian cover in La Parguera comprised 25 genera (Figure 3.29). The most abundant coral genera was *Montastraea*, followed by *Porites, Agaricia, Diploria* and *Siderastrea*. Following the Caribbean-wide bleaching event of 2005, bleaching in February 2006 was observed at 84% of all surveyed reef sites (n=37). Incidences of bleaching had declined by the August 2006 surveys, when bleached coral was observed at 10% of surveyed reefs (n=5).

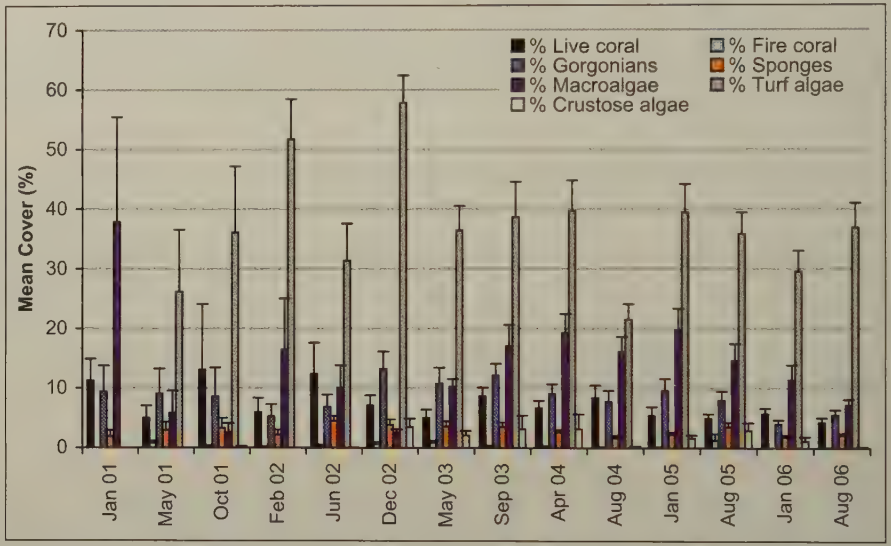


*Figure 3.28. Comparison of mean (± SE) percent cover of benthic cover groups among years. Source: CCMA-BB.*

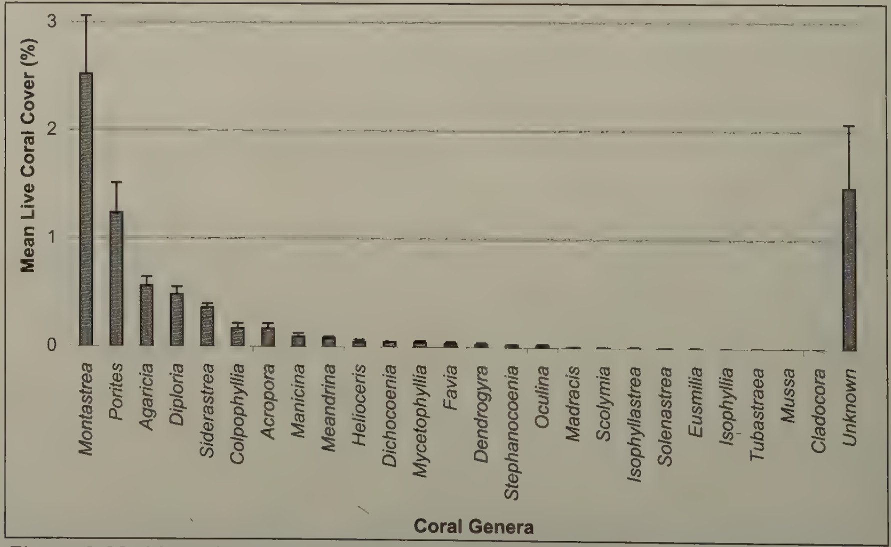


*Figure 3.29. Mean (± SE) percent live coral cover of coral genera on randomly selected reef/hardbottom sites in study area. Source: CCMA-BB.*

## Characterization of Vieques, PR

CCMA-BB has also recently initiated a monitoring project focused on coral reef ecosystems near the island of Vieques, in cooperation with NOAA's Office of Response and Restoration. CCMA-BB completed a two-week mission in May 2007 to characterize the fish and benthic communities on reef and hardbottom habitats at 75 sites around Vieques, Puerto Rico using the same methods as employed at other coral ecosystem monitoring locations monitored by the group. Analytical results from the Vieques surveys are under development, and summary information will be provided in a future version of this report.

In conjunction with the field monitoring, the CCMA-BB is completing a nearshore benthic habitat map for Vieques using IKONOS satellite imagery. Results and interpretation from both components will be included in an integrated assessment of the marine resources of Vieques. The report, raw data, imagery, and delineated maps will be distributed on a CD and online. More information can be found at http://ccma.nos.noaa.gov/ecosystems/coralreef/vieques.html.

## Mid- and Deepwater Seafloor Characterization in the U.S. Caribbean

Since 2004, NOAA's CCMA-BB has conducted annual scientific research missions on the NOAA ship *Nancy Foster* to explore, and as another component of NCREMP, characterize U.S. Caribbean habitats from 10 to 1,000 m using high-resolution bathymetry and backscatter data with complementary video and still imagery. Since 2006, the mapping missions have also included parts of the Puertorrican shelf in an effort to fill gaps in CCMA-BB's previous mapping effort (Kendall et al., 2001) and integrate abiotic and biotic data in order to extend the benthic habitat maps to mid- and deepwater areas (Table 3.9). Missions have focused on areas north of St. Croix, areas south of St. Thomas and parts of southwestern Puerto Rico, including La Parguera, Mona Island, Bajo de Sico and Abrir la Sierra bank, all of which contain MPAs (Figure 3.30). As part of this effort, scientists have collected 470 km$^2$ of multibeam data, conducted 125 km of ROV transects and captured thousands of images at 84 drop camera sites (http://ccma.nos.noaa.gov/products/biogeography/usvi_nps/data.html). The project aims to meet the identified need for detailed bathymetric models of the Puerto Rican seafloor, as well as for continued benthic habitat characterizations and ecological inventories beyond the depth limits of optical remote sensing technologies. Integration of acoustical mapping technologies with traditional optical sensing methods enables the creation of near-seamless habitat maps from the shoreline to 1,000 m water depth.

*Table 3.9. Survey effort for NOAA Biogeography Branch's mid and deepwater seafloor mapping around Puerto Rico. Source: CCMA-BB.*

| METRICS | 2007 | 2006 | TOTAL |
|---|---|---|---|
| Area Ensonified (km$^2$) | 115 | 63 | 178 |
| Ship Track lines (km) | 1,084 | 298 | 1,382 |
| ROV Track lines (km) | 0 | 14 | 14 |
| # Drop Camera Sites | 84 | 0 | 84 |

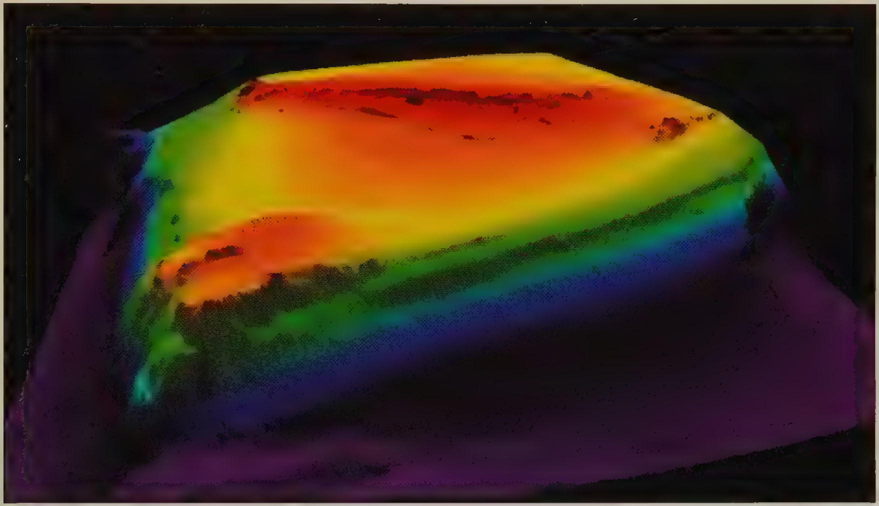


*Figure 3.30. Multibeam bathymetry of Bajo de Sico, Mona Passage was collected by scientists on the NOAA ship* Nancy Foster *in 2007. Source: CCMA-BB.*

Several Web-accessible products have been generated from the project. A Benthic Habitat Viewer database comprising over 9,000 underwater seafloor images, along with information on each image's location, biological inventory, benthic habitat characterization, geomorphological structure, and seafloor terrain characteristics (i.e., bathymetry, slope, and rugosity), is available online at http://www8.nos.noaa.gov/bhv/bhvMapBrowser.aspx. Multibeam bathymetric data are in the public domain in a variety of formats including ASCII XYZ text files, ESRI Grids and georeferenced TIFF images. Mosaics of multi-beam backscatter data that were geometrically and radiometrically corrected are also available online as geotiffs and are ready for use in a GIS. Other derived products include ESRI grids of bathymetric slope and rugosity. Slope was calculated as degrees inclination above the horizontal with the ESRI ArcGIS Spatial Analyst extension. Rugosity, a common index of bottom complexity, was generated with the Benthic Terrain Modeler, an ArcGIS toolset developed by the University of Oregon. For more information and free access to the acoustic and optical data, please visit http://ccma.nos.noaa.gov/products/biogeography/usvi_nps/overview.html.

## ASSOCIATED BIOLOGICAL COMMUNITIES

### *National Coral Reef Ecosystem Monitoring Program (NCREMP): Puerto Rico Reef Fish Monitoring*

*Methods*

Quantitative and qualitative surveys of diurnal, non-cryptic reef fishes have been conducted annually as part of the biological baseline characterizations and monitoring of coral reef communities in Puerto Rico. Reef fishes were surveyed using a belt-transect technique. Transects 10 m long and 3 m wide (30 $m^2$ survey area) centered over the linear transects were used to characterize the reef benthic community. A total of five belt transects were surveyed at each reef station.

*Results and Discussion*

A total of 171 species of diurnal, non-cryptic fish species have been identified under NCREMP. Mean fish abundance within 30 $m^2$ belt transects at reef sites ranged from a maximum of 444.6 individuals per transect at Puerto Canoas Reef, Isla Desecheo to a minimum of 56.2 individuals per transect at Tres Palmas Reef in Rincon (Table 3.10). Likewise, the mean number of fish species per 30 $m^2$ transect was highest (31.6 species) from Puerto Canoas Reef and lowest (10.6 species) from the Tres Palmas Reef. The highest number of diurnal, non-cryptic fish species observed within the five belt transect surveys was also from Puerto Canoas Reef with a total of 50 species.

*Table 3.10. Mean abundance and species richness of fishes within belt-transects at reefs included in the coral reef monitoring program between 1999–2007. Source: Garcia-Sais et al., 2001a, 2001b, 2001c, 2001d, 2005c; 2006, 2007.*

| REEF | SITE | DEPTH (m) | MONITORING PERIOD | MEAN SPECIES (PER 30 $m^2$) | MEAN ABUNDANCE (PER 30 $m^2$) | MEAN LIVE CORAL COVER (%) | MEAN RUGOSITY (m) |
|---|---|---|---|---|---|---|---|
| Tres Palmas | Rincon | 5 | 2004-2007 | 10.6 | 56.2 | 37.6 | 2.6 |
| Tres Palmas | Rincon | 10 | 2004-2007 | 17.6 | 118.8 | 19.2 | 1.7 |
| Tres Palmas | Rincon | 20 | 2004-2007 | 24.3 | 334.0 | 21.0 | 3.2 |
| Puerto Botes | Isla Desecheo | 15 | 2004-2007 | 23.8 | 216.3 | 14.2 | 3.0 |
| Puerto Botes | Isla Desecheo | 20 | 2000/2004-2007 | 27.4 | 170.8 | 36.4 | 3.8 |
| Puerto Canoas | Isla Desecheo | 30 | 2004-2007 | 31.6 | 444.6 | 39.8 | 4.2 |
| Tourmaline | Mayaguez | 10 | 1999/2004-2007 | 22.6 | 95.2 | 43.1 | 3.6 |
| Tourmaline | Mayaguez | 20 | 2004-2007 | 24.6 | 196.4 | 27.1 | 5.3 |
| Tourmaline | Mayaguez | 30 | 2004- 2007 | 20.7 | 196.0 | 13.9 | 5.7 |
| Cayo Coral | Guanica | 10 | 1999/2005-2007 | 21.0 | 59.0 | 16.6 | 4.4 |
| Caja de Muerto | Ponce | 7 | 1999/2005-2007 | 23.8 | 160.6 | 16.4 | 5.6 |
| Derrumbadero | Ponce | 20 | 2001/2005-2007 | 23.4 | 128.6 | 26.4 | 3.0 |

The Rincon and Isla Desecheo reef systems presented a pattern of increasing number of fish species per transect with increasing depth. This pattern was inconsistent at the Mayaguez site because richness of fish species declined at the 30 m depth, relative to shallower stations. Although the reef system at Mayaguez (30 m) presented the highest rugosity (mean: 5.7 m) among reefs surveyed, live coral cover was lower than at shallower reef stations. García et al. (2005) demonstrated that live coral cover was the best predictor of fish species richness during the baseline surveys at 57 reefs. A particular exception to this model is the case of the Tres Palmas Reef (5 m), which is an *Acropora palmata* biotope. This reef had the lowest mean number of fish species per transect (10.6 species) with a relatively high mean substrate cover by live corals (37.6%), but very low rugosity (Table 3.10). It appears that the high energy environment at this shallow reef may allow development of elkhorn coral but limit the number of fish species adapted to withstand such stress. Also, the low reef rugosity implies reduced habitat heterogeneity, with implications for a relatively lower complexity of the fish species assemblage.

During the monitoring program, fish populations have exhibited a temporal pattern of stable species richness and taxonomic composition, but a trend of declining abundance within belt transects was statistically significant in seven out of the 12 reef stations surveyed (García-Sais et al., 2007). Variations between surveys were mostly driven by fluctuations in the abundance of small but numerically dominant species which exhibit highly aggregated distributions, such as the masked goby (*Coryphopterus personatus*) and the blue chromis (*Chromis cyanea*). It is uncertain at this point if such reductions of reef fish abundance in coral habitats are related to the marked decline of live coral cover documented by the monitoring program. Although in low abundance, large demersal fishes that have been overfished during the last decades have been detected at several reefs during the surveys. These include yellowfin, tiger, goliath and Nassau groupers (*Mycteroperca venenosa*, *M. tigris*, *Epinephelus itajara* and *E. striatus*), as well as the cubera, dog and mutton snappers (*Lutjanus cyanopterus*, *L. jocu* and *L. analis*).

## *NOAA's NCREMP and Caribbean Coral Reef Monitoring Project: La Paguera*

The goals and objectives of CCMA-BB's Caribbean Coral Reef Ecosystem Monitoring Project are introduced in the Benthic Habitats section of this chapter.

### *Methods*

Survey sites are selected using a stratified random sampling design that incorporates strata derived from CCMA-BB's nearshore benthic habitat map (Kendall et al., 2001) to ensure comprehensive coverage of the study region. At each site, fish, macro-invertebrates, water quality and habitat information are quantified following standardized protocols that are available online at http://ccma.nos.noaa.gov/ecosystems/coralreef/reef_fish/protocols.html. CCMA-BB's field methodology consists of two complementary components. A 25 x 4 m belt transect is used to quantify fish species size and abundance at sites chosen through random stratified sampling. The second component involves taking detailed habitat measurements at five locations along the same belt transect. Fish data is then analyzed in conjunction with large-scale habitat information to identify spatial patterns in community structure.

### *Results and Discussion*

Since 2001, a total of 1,035 locations have been sampled in southwestern Puerto Rico (includes coral reef/hardbottom, mangrove and seagrass). In the last reporting effort (2005), CCMA-BB demonstrated how measures of fish community structure (abundance, species richness, and species diversity) differed among the habitat types sampled. In contrast, the goal of this report is to characterize the temporal patterns in these metrics as well as for metrics of several key taxonomic groups and species.

Species richness and Shannon's species diversity index showed little annual change between 2001 and 2006 (Figure 3.31). Although richness was slightly higher than average in September 2003 and slightly lower than average in February 2002 and 2006, it was relatively constant over the survey period. Similarly, there was no noticeable trend in species diversity. Community biomass and abundance exhibited moderate variation between survey periods (Figure 3.32). Although there was no overall trend between 2001 and 2006, there was a large spike in community biomass in December 2002; this can be attributed to the sighting of a large tiger shark (*Galeocerdo cuvier*), which accounted for 21% of the biomass estimate for the entire mission. Community abundance was usually higher during summer surveys than those conducted during the winter and early spring, although this was not consistent across all years. The highest mean abundance occurred in August 2004, followed by September 2003 and June 2002.

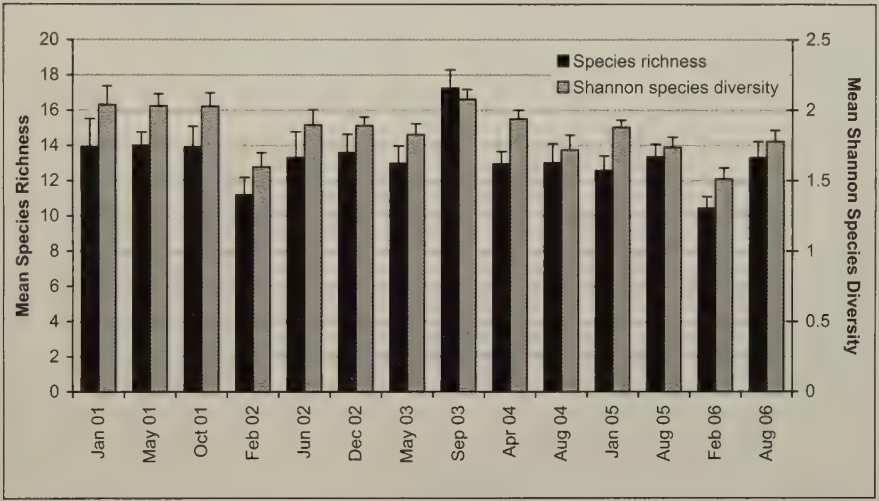


*Figure 3.31. Fish species richness and diversity at La Parguera study area. Source: CCMA-BB.*

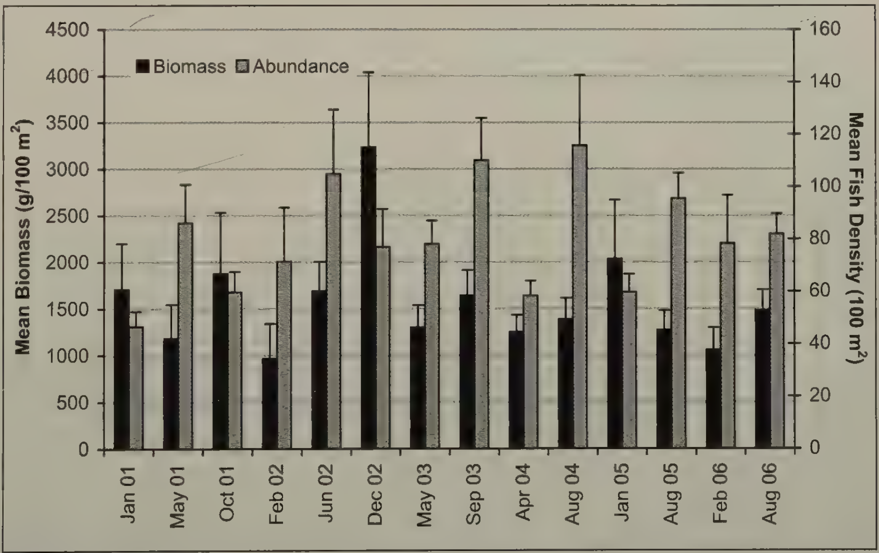


*Figure 3.32. Mean (± SE) fish community biomass and abundance in La Parguera study area. Source: CCMA-BB.*

Metrics for trophic and taxonomic components of the fish community were more variable than for changes in the whole community. None of the metrics showed identifiable seasonal patterns or long-term trends. Herbivore biomass (H) was approximately two times greater than piscivore biomass (P; mean 1.22 and 0.58 g/100 m$^2$ transect, respectively) and was significantly less variable (CV 29 and 83, respectively). Their ratio (H:P) fluctuated between one and eight, and in October 2003 piscivore biomass was slightly greater than herbivore biomass (Figure 3.33). Fluctuations in the H:P ratio were directly linked to whether or not large (>50) schools of jacks (family Carangidae) or snappers (family Lutjanidae) were observed during surveys.

The fish community surveyed in the study area consists of 57 taxonomic families (Figure 3.34). Biomass and abundance are unevenly distributed throughout these taxonomic groupings. Over 90% of individuals and biomass come from seven and 14 families, respectively. The majority of surveyed individuals come from one family (Clupidae), which make up less than 1% of the biomass. Large schools of juvenile clupeiids, often numbering in the 1,000s, were characteristic at many mangrove sites. Parrotfishes (family Scaridae) were typically the most numerically abundant group at reefs/hardbottom, followed by wrasses (family Labridae), damselfishes (family Pomacentridae), gobies (family Gobiidae) and surgeonfishes (family Acanthuridae). Grunts, gobies, parrotfishes and wrasses were the dominant taxa on softbottom substrates.

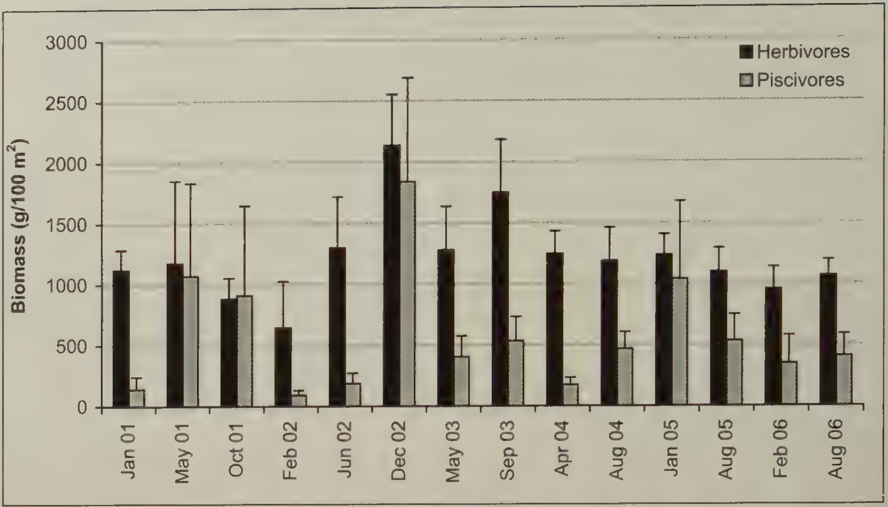


*Figure 3.33. Herbivore and piscivore biomass estimates from all surveys in La Parguera study area. Source: CCMA-BB.*

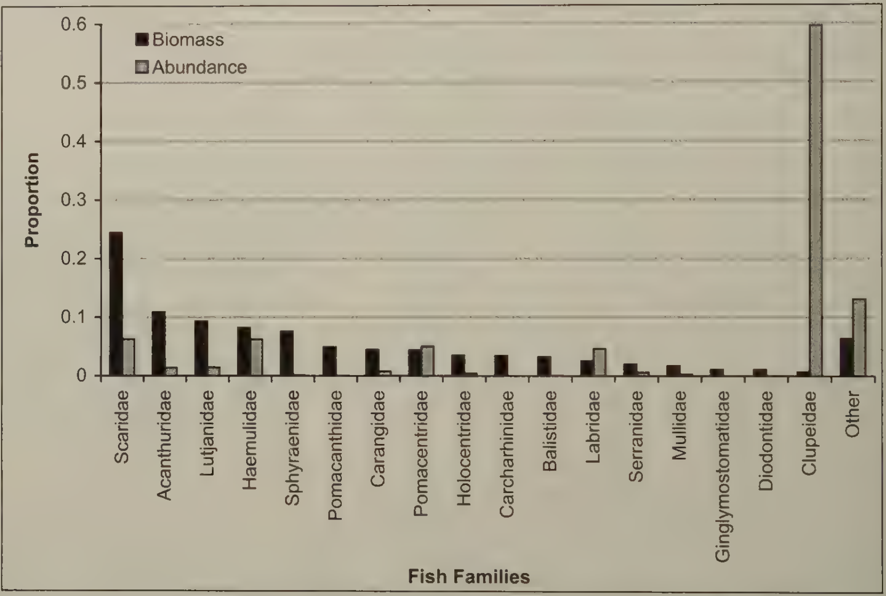


*Figure 3.34. Proportional distribution of biomass and abundance of major families in La Parguera study area. Source: CCMA-BB.*

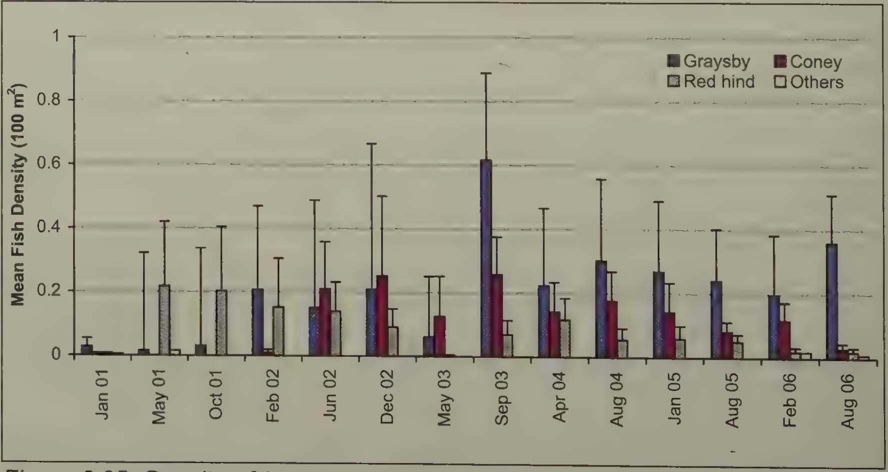


*Figure 3.35. Density of large grouper (*Epinephelus, Cephalopholis *and* Mycteroperca *spp.) from all surveys in La Parguera study area. Source: CCMA-BB.*

The majority of fished large-bodied groupers (Genera: *Epinephelus*, *Cephalopholis* and *Mycteroperca*) were detected on reef/hardbottom habitats (98.3%, n=238). Community structure of fished groupers has shifted over time. Initially red hind (*E. guttatus*) were the most prevalent species, then for a time Coney (*C. fulvus*), and most recently Graysby (*C. cruentatus*; Figure 3.35). Since September 2003, Graysby have generally made up well over 50% of the fished groupers, and in August 2006 (the latest survey analyzed) Graysby were >90% of all fished groupers. Nassau grouper (*E. striatus*), black grouper (*M. bonaci*) and rock hind (*E. adcensionis*) have also been observed, but are very rare (six sightings in 1,035 sites). Almost no coney were detected during the first four synoptic surveys (January 2001 to June 2002), but a surge was detected in June 2002. Following the surge, there has been a downward trend in density. Similarly, the density of red hind has decreased continuously since 2001.

Snappers (family Lutjanidae) were detected frequently among all investigated habitats, including reef/hardbottom, sand/seagrass and mangroves. The majority of individuals were observed among mangroves (Figure 3.36), except for yellowtail snapper (*Ocyurus chrysurus*), which was frequently detected among reef/hardbottom habitats. Relatively few mature adult snappers were observed in any habitat. Snapper densities in mangroves were generally between 10-20 individuals per 100 m², but in August 2006 densities approached 60 individuals per transect (Figure 3.36). Long-term trends or seasonal patterns of density were not observed. When densities of juvenile and adult life-stages were examined separately, the ratio of juvenile to adult yellowtail snapper showed an increasing trend (i.e., more juveniles than adults in later surveys).

Grunts (family Haemulidae) were a conspicuous component of the reef fish community in mangroves. They were also seen in reef/hardbottom and softbottom habitats but usually much less frequently and in lower numbers (Figure 3.37). Most individuals were tomtates (*Haemulon aurolineatum*) french grunts (*H. flavolineatum*), or bluestriped grunts (*H. sciurus*). Mean densities in mangroves ranged between 15 and 75 individuals per transect. Densities were significantly lower in surveys conducted between April and August compared to other months (Kruskal-Wallis; $p<0.01$). Generally, density of grunts on softbottom habitats vary between five and 30 individuals per transect, but in August 2005 and February 2006 density estimates were exceptionally high. In February 2006, the average density in softbottom habitats surpassed the density in mangrove habitats. Densities on reef/hardbottom habitats were much lower, generally less than five individuals per transect. In August 2004, unusually large schools of juvenile grunts (length <5 cm) were observed at reef/hardbottom sites and the density of grunts surged to 20 individuals per transect.

Parrotfishes (Scaridae family) made up more of the reef fish community biomass than any other family in the study area. They are moderately abundant, but are generally larger bodied than most other families. Density is generally greater on hardbottom sites, but during June 2001 was greatest in mangroves and in January 2005 was greatest on softbottom habitats (Figure 3.38). In all habitats combined density typically ranges from 25 to 45 individuals per transect. An unusually high density was found during September 2003. The main reason for this surge was the detection of several large schools of princess parrotfish (*Scarus taeniopterus*), which were infrequently sighted in other surveys. Investigation of the princess parrotfish and other species did not reveal any seasonal patterns or long-term trends.

Hogfish (*Lachnolaimus maximus*) are an economically important component of the wrasse community (family Labridae). Wrasses are generally rare, but the data suggests an increasing trend in their density over time. A surge in juvenile density was detected in May and September 2003 surveys. Afterward, mature adult hogfish densities were higher than before the pulse, except for in April 2004 and January 2005. In August 2006, the latest analyzed survey, the hogfish density estimate was the greatest it has ever been.

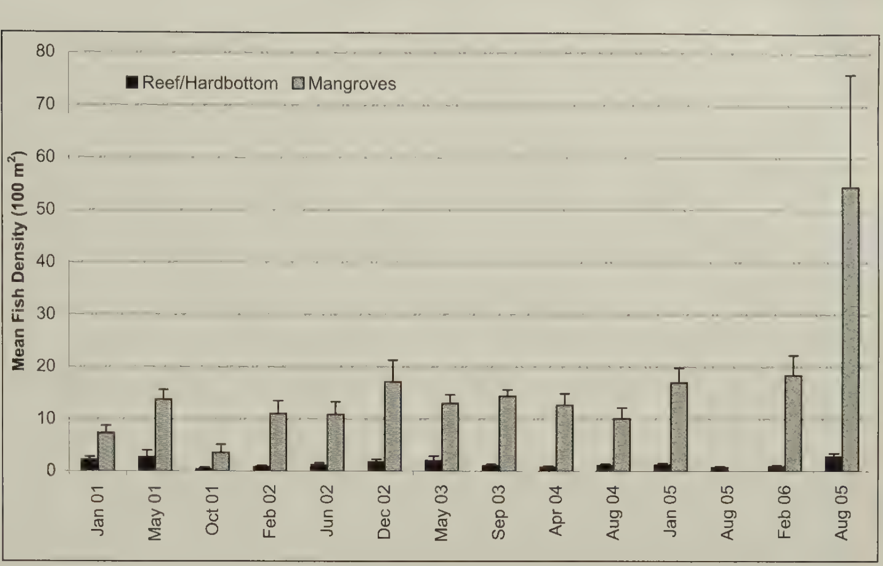


*Figure 3.36. Density estimates of snapper (family Lutjanidae) in mangrove, softbottom and reef/ hardbottom habitats. Source: CCMA-BB.*

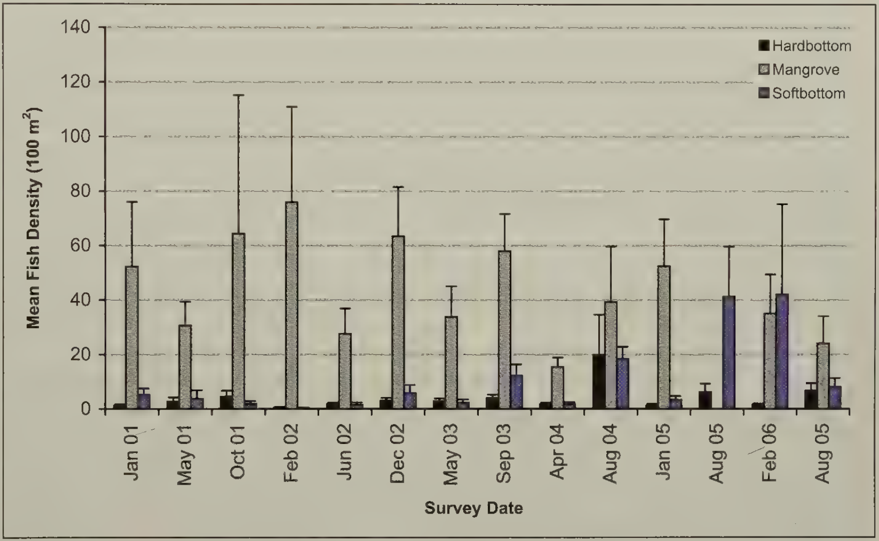


*Figure 3.37. Density estimates of grunts (family Haemulidae) in mangrove, softbottom, and reef/hardbottom habitats. Source: CCMA-BB.*

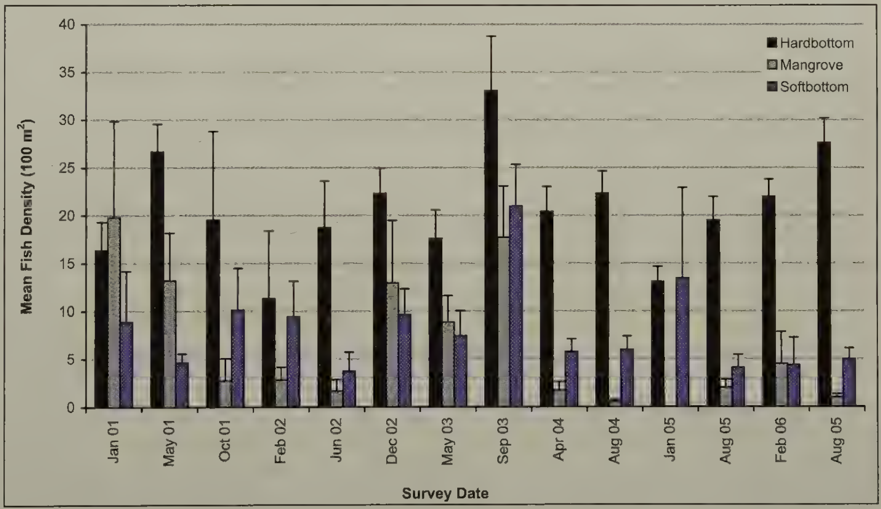


*Figure 3.38. Density estimates of parrotfish (family Scaridae) in mangrove, softbottom and reef/hardbottom habitats. Source: CCMA-BB.*

## CURRENT CONSERVATION MANAGEMENT ACTIVITIES

Several coastal areas with extensive coral reef development have been designated as MPAs by the DNER and represent a first step towards conservation of Puertorrican coral reef resources. In total, the government of Puerto Rico has established 37 MPAs that fall within four categories: natural reserves, marine reserves, no-take zones, and state forests. There are 31 natural reserves, 26 of which are administered by the DNER. The Conservation Trust of Puerto Rico administers four natural reserves and the Puerto Rico National Parks Company administers one. DNER also administers two marine reserves, a no-take zone in Condado Lagoon, and a coastal state forest that is the only one not also designated a natural reserve. In addition to the 26 sites under Puerto Rico's jurisdiction, there are four MPAs that the Puerto Rico government jointly manages with the federal government. These are the Jobos Bay National Estuarine Research Reserve which is jointly managed with NOAA; and three seasonal closure areas, Tourmaline Bank, Bajo de Cico and Abrir la Sierra which are jointly managed with the CFMC. Abrir la Sierra is in federal waters. These areas protect spawning aggregations of red hind (*Epinephelus guttatus*) off the west coast of Puerto Rico. All fishing is prohibited in these areas from December 1 through February 28.

There are two Natural Reserves that contain no-take areas. These are the Canal Luis Peña Natural Reserve and the Mona and Monito Islands Natural Reserve (Wusinich-Mendez et al., 2007). The no-take zone around Mona and Monito Islands was established in 2004 under Puerto Rico Fishing Regulation No. 6768, amended in March 2007 (Regulation 7326). The no-take zone includes all of the insular platform around Mona and Monito Islands except for the area between Punta Arenas and Cabo Barrionuevo where recreational hook-and-line fishing is permitted. In all other Natural Reserves, fishing is prohibited in zones designated as bathing areas by the Puerto Rico Planning Board.

The DNER has a Maritime Ranger Unit of approximately 200 rangers that enforce local coral reef, navigation and fishery regulations, as well as the regulations that are specific to certain MPAs. Within the unit there are, at present, a Coral Reef Ranger Task Force and a Fisheries Task Force. The Coral Reef Task Force is responsible for special projects such as ship groundings and coral reef restoration. The Fisheries Task Force consists of Rangers who have been deputized to enforce both local and federal fishing regulations. DNER is currently planning to unite these two units such that they can enforce local and federal regulations for the protection of all marine species. A joint enforcement agreement was signed between DNER and NOAA in 2007 enabling the Rangers to be deputized and providing additional federal funding for enforcement work.

The DNER is working to develop comprehensive management plans for its MPAs because, at present, none has an approved management plan. Draft management plans have been completed for the Canal Luis Peña Natural Reserve, La Cordillera Reefs Natural Reserve, and Tres Palmas Marine Reserve. These plans now require coordination with the PR Environmental Quality Board for the preparation of environmental documents and public hearings and public comment periods, final approval by the Puerto Rico Planning Board, and adoption of the plans as part of the Island-wide Land Use Plan. A total of 11 natural reserves have field officers and managers who are physically present within the facilities and oversee day-to-day management activities (Wusinich-Mendez et al., 2007) based on current regulations for the protection of marine resources.

The CFMC and NOAA have also collaborated with DNER scientists and managers to significantly revise Puerto Rico's fisheries regulations and federal regulations in response to the Sustainable Fisheries Act and revisions to the Magnuson-Stevens Fishery Conservation and Management Act. The revised regulations are directed at protecting the integrity of essential fish habitats, including coral reefs, seagrass beds and coastal wetlands, by regulating fishing activities through the establishment of quotas, no-take areas, and seasonal or permanent fishing closures for overexploited species including red hind (*E. guttatus*), mutton snapper (*Lutjanus analis*) and queen conch (*Strombus gigas*). The revisions to the Puerto Rico Fishing Regulations were published in March 2007.

Through collaborative efforts funded by the NOAA CRCP through NOAA Fisheries Caribbean Field Office, DNER was able to install navigational markers on shallow coral reefs and additional mooring buoys in La Parguera Natural Reserve in 2006 and 2007 to minimize impacts to shallow seagrass beds and coral reefs caused by accidental groundings and anchoring. DNER also installed mooring buoys in seagrass beds in the Canal Luis Peña Natural Reserve in 2007 and completed educational brochures for users of these two reserves regarding the importance of appropriate anchoring and navigation to protect marine resources. These efforts will continue in 2008 with the installation of mooring buoys and educational signage and an educational campaign aimed at recreational boaters to protect coral reefs and seagrass beds in La Cordillera Reefs Natural Reserve. Collaborative efforts funded by CRCP also included a partnership between NOAA Fisheries Caribbean Field Office and the Puerto Rico Tourism Company and Puerto Rico National Parks Company beginning in 2005. This campaign to educate public beachgoers regarding the importance of marine resources such as MPAs, coral reefs, and seagrass beds at the beaches is still ongoing and includes an educational segment on a local television program geared to local tourists, a public service announcement that aired in movie theaters and on local television, a full page newspaper announcement, educational brochures, and educational signage at public beaches.

# OVERALL CONCLUSIONS AND RECOMMENDATIONS

The initial objectives of the U.S. Coral Reef Initiative Program for Puerto Rico, such as the mapping of benthic habitats (including coral reefs), conducting baseline quantitative characterizations of coral reef communities, routine monitoring of selected reef sites, and launching of a coral reef public awareness and outreach program have been fully addressed and achieved to a significant level due to the combined efforts of local government, federal agencies, public and private universities and NGOs.

Continued efforts directed towards the mapping and biological characterization of benthic habitats by the CFMC and CCRI with technical and funding support from NOAA have significantly expanded our knowledge of the geographic distribution and extent of coral reef ecosystems in Puerto Rico. Of particular relevance has been the reporting of mesophotic reefs associated with submerged platforms at depths between 45-70 m at Isla Desecheo (Agelas Reef) and at depths of 45–90 m at Bajo de Sico in Mona Passage. These reefs are important residential and/or foraging habitats for large, commercially exploited reef fish populations and serve as recruitment habitats for a variety of shallow reef fish populations. The Puerto Rico Coral Reef Ecosystem Monitoring Program, sponsored by NOAA and administered by the DNER since 1999, is fully implemented and is achieving its goals in collaboration with federal and local governmental agencies and marine scientists from research institutions. A total of 12 reefs from six MPAs are presently included in the annual monitoring program. These include reef sites at Isla Desecheo, Rincón, Mayagüez, Guánica, Isla Caja de Muerto and Ponce. Data produced by the program has shown that the sessile-benthic community at some of the reef systems evidenced statistically significant differences of live coral cover between annual monitoring surveys. Expansion of the existing coral reef monitoring program sponsored by CCRI-NOAA and DNER is underway in order to determine whether this pattern exists in other MPAs.

A sharp decline in live coral cover was detected between surveys in 2005 and 2006 and has been attributed to the severe coral bleaching event in the U.S. Caribbean that began in the fall of 2005. The coral bleaching event coincided with an extended period of elevated sea SSTs. Live coral cover during the most recent 2007 monitoring survey presented a pattern of mild reductions relative to 2006 levels for almost all reef sites monitored. Declines of live coral cover between the 2006 and 2007 surveys were statistically significant (ANOVA; $p<0.05$) at Tourmaline Reef 20 m in Mayaguez, and at Puerto Canoas Reef 30 m in Isla Desecheo. Such reductions of live coral cover appear to be lingering effects of the 2005 coral bleaching event and warrant continued observation. In addition to the decline in (total) live coral cover at the reef community level, severe tissue loss and prolonged bleaching stress resulted in reproductive collapse during the 2006 mass spawning cycle for boulder star coral, *Montastraea annularis* (complex), lettuce corals (*Agaricia* spp.), staghorn coral (*A. cervicornis*) and cactus corals (*Mycetophyllia* spp.).

Fish populations from natural reserves presented a general trend of declining abundance. Reductions in fish abundance were statistically significant in seven out of the 12 reef stations surveyed. Variations between surveys were mostly associated with reductions in abundance of numerically dominant populations that exhibit highly aggregated distributions in the immediate vicinity of live coral heads, such as the masked goby (*Coryphopterus personatus*) and the blue chromis (*Chromis cyanea*). It is uncertain at this point if such reductions in abundance of reef fishes closely associated with coral habitats are related to the recent massive coral mortality exhibited by reef systems. Although in low abundance, large demersal (top predator) fishes were detected during active search surveys in several reefs. These included yellowfin, tiger, goliath and Nassau groupers (*Mycteroperca venenosa*, *M. tigris*, *Epinephelus itajara* and *E. striatus*, respectively), as well as the cubera, dog and mutton snappers (*Lutjanus cyanopterus*, *L. jocu* and *L. analis,* respectively).

Overfishing has been implicated in the decline in landings of coral reef associated fish and shellfish species. For this reason, 2005 amendments to the Fishery Management Plans of the CFMC included the year-round prohibition on fishing of queen conch (*Strombus gigas*) in federal waters around Puerto Rico. The CFMC also established stricter gear controls as part of these amendments in response to data related to the impacts of bottom-tending gears on important benthic habitats, particularly corals.

Shipping activity continues to pose a threat to the coral reef ecosystem as evidenced by events such as the grounding of the M/T *Margara*, a 228-m tanker that ran aground on the reefs of Guayanilla Bay, southwestern Puerto Rico on April 27, 2006. The damage was extensive and estimated to have impacted up to 8,500 $m^2$ of reef. This was the second grounding in the same area within one year, indicating that additional aids to navigation or other measures need to be implemented to reduce the risk of large vessel groundings to coral reefs.

Coastal development continues to pose a significant threat to the coral reef ecosystem in Puerto Rico as evidenced by data on the evaluation of proposed water resources development projects from the NOAA Fisheries Caribbean Field Office. Docks, housing developments, and marinas were consistently the most common projects proposed and 69% of these projects had the potential to impact seagrass beds, coastal wetlands, and corals. In addition, despite educational efforts by numerous entities, including DNER, NOAA, Sea Grant, and NGOs, there continues to be an increase in unauthorized construction and land clearing activities that result in impacts to the coral reef ecosystem. Thus, there is a need for continuing public education and outreach and a change in focus in existing programs in order to have a greater impact on increasing public awareness of the importance of the coral reef ecosystem.

Recent studies of the impacts of recreational boating indicate that heavily visited areas are likely to lose seagrass due to anchoring in La Cordillera Reefs Natural Reserve, while propeller scarring and propeller wash resulted in the loss of seagrass in La Parguera Natural Reserve. An ongoing study in Culebra also indicates that dock construction and associated boating activity results in the loss of shallow seagrass beds. The results of these studies indicate a need for stricter management of recreational boating activity related to the construction of docks and marinas and the designation of anchorage areas, as well as the enforcement of existing laws and regulations.

## Recommendations

After the acute and unprecedented loss of live coral from Puertorrican reefs in 2005-2006 induced by elevated SSTs, government agencies, scientists, NGO's and the public need to promote policies to avoid further degradation of coral reefs. Anticipating that further coral bleaching, disease, and mortality will likely accompany future elevated SST events, strategies for restoring reefs with heat tolerant strains of corals must be considered and evaluated. Therefore, research directed towards the physiological, genetic, cellular-molecular and general ecological aspects of heat tolerant corals should be supported. Considering that the warm water mass that induced such mass coral mortality was associated with the pass of a mesoscale anticyclonic eddy, further attention should be given to oceanographic processes as they appear to be of critical importance to coral reef ecosystem health. Coral bleaching response action plans should be developed and incorporated into coral reef monitoring programs to allow for a rapid and efficient implementation for characterization of affected reef systems during future events. In addition, management measures to reduce other stresses to the coral reef ecosystem from human activities need to be developed and implemented in order to assist in lessening the impact of climate change stressors such as rising SSTs.

One of the main concerns regarding the health of the coral reef ecosystem in Puerto Rico is the unknown recreational carrying capacity of these systems due to impacts from activities such as recreational fishing, anchoring and boating, trampling of corals and seagrass during snorkeling and bathing activities, and the contamination of the water by garbage, petroleum products, and other substances. Guidelines for recreational use of coral reefs and associated ecological systems within MPAs are needed and should be widely disseminated. There has been an increasing trend of utilization of coastal resources by local and foreign tourists without consideration of the maximum level of resource utilization that the systems can withstand. There is a need to establish a maximum number of boats allowed at each reef or within each MPA and guidelines for compatible use of marine resources in order to ensure that recreational activities are sustainable.

There is a need to monitor coral reef associated fisheries under management and to increase the enforcement effort in Puerto Rico, particularly in the existing seasonal and permanent closed fishing areas. A comprehensive assessment of the impact of recreational fishing activities on reef fish, queen conch, and spiny lobster populations must be performed as data on the contribution of this fishery to species' stock status are relatively few. The queen conch population needs to be assessed to determine its reproductive viability and role of the deeper water populations in rebuilding the fishery in state waters since the closing of the fishery in federal waters in 2005. This assessment should be performed first in the closed areas off the west coast of Puerto Rico as part of a monitoring effort to document the rebuilding of managed stocks.

Exploration, mapping, and biological characterization of deep reef systems are needed around the Puerto Rico shelf but particularly within the 30-50 m depth range off the eastern and western coasts. Preliminary surveys indicate that mesophotic reefs occupy much larger areas than previously thought. Ongoing studies have identified these reefs as critically important resident, foraging, reproductive and recruitment habitats for commercially exploited fish and listed sea turtle populations.

Management activities, which are possibly the most critical components in maintaining a healthy coral reef ecosystem due to their relationship in supporting enforcement and compliance, encouraging community involvement, and increasing public awareness, must be more strongly supported. Management and research need to be better integrated in order to ensure that management actions are driven by science and research efforts focus on obtaining the information managers need to adequately conserve trust resources. It is also recommended that the topic of marine ecology and resource conservation be incorporated into the science curricula at all educational levels in Puerto Rico through a concerted effort by DNER and other local and federal partners to work with the Puerto Rico Department of Education to promote stewardship of Puerto Rico's marine resources.

# REFERENCES

Acropora Biological Review Team. 2005. Atlantic Acropora Status Review Document. Report to NOAA National Marine Fisheries Service, Southeast Regional Office. Miami, FL. 152 pp. + Appendices. http://sero.nmfs.noaa.gov/pr/pdf/050303%20status%20review.pdf.

AGRRA (Atlantic and Gulf Rapid Reef Assessment). 2003. AGRRA surveys in Eastern Puerto Rico, including Fajardo, Culebra, and Vieques. Final report submitted to Office of Office of Habitat Conservation, NOAA National Marine Fisheries Service. 25 pp.

Aguilar-Perera, J.A. 2004. Coastal habitat connectivity of reef fishes from southwestern Puerto Rico. Ph.D. Dissertation. Department of Marine Science, University of Puerto Rico at Mayagüez. Mayagüez, PR. 143 pp.

Ault, J.S., S.G. Smith, J. Luo, M.E. Monaco, and R.S. Appeldoorn. In review. Length-Based Assessment of Sustainability Benchmarks for Coral Reef Fishes in Puerto Rico. Environ. Conserv.

Antonius, A. 1973. New observations on coral destruction in reefs. p. 3. In: Tenth Meeting of the Association of Island Marine Laboratories of the Caribbean: Abstracts. University of Puerto Rico. Mayagüez, PR.

Armstrong, R., H. Singh, J. Torres, R. Nemeth, A. Can, C. Roman, R. Eustice, L. Riggs, and G. Garcia-Moliner. 2006. Characterizing the deep insular shelf coral reef habitat of the Hind Bank marine conservation district (U.S. Virgin Islands) using the SeaBED autonomous underwater vehicle. Cont. Shelf Res. 26: 194-205.

Ballantine, D., E. Weil, and H. Ruiz. 2005. Coralline white band syndrome: a new affliction affecting coralline algae in the Tropical Atlantic. Coral Reefs 24(1): 117.

Bejarano-Rodríguez, I. 2006. Relationships between reef fish communities, water and habitat quality on coral reefs. M.S. Thesis. University Puerto Rico at Mayagüez. Mayagüez, PR. 51 pp.

Bruckner, A.W. 1999. Black-band disease (BBD) of scleractinian corals: occurrence, impacts and mitigation. Ph.D. Dissertation, University Puerto Rico. Mayagüez, PR. 286 pp.

Bruckner, A.W. and R.J. Bruckner. 1997. Outbreak of coral disease in Puerto Rico. Coral Reefs 16: 260.

Bruckner, A.W. and R.J. Bruckner. 2006. Chapter 14: Restoration outcomes of the *Fortuna Reefer* Grounding at Mona Island, Puerto Rico. pp. 257-269. In: W.F Precht (ed.). Coral Reef Restoration Handbook: The Rehabilitation of an Ecosystem Under Siege. CRC Press. Boca Raton, FL. 339 pp.

Burke, L. and J. Maidens. 2004. Reefs at risk in the Caribbean. World Resources Institute, Washington, DC. 81 pp.

Caribbean Fishery Management Council (CFMC). 1996. Regulatory Amendment to the Fishery Management Plan for the Reef Fish Fishery of Puerto Rico and the United States Virgin Islands Concerning Red Hind Spawning Aggregation Closures Including a Regulatory Impact Review and an Environmental Assessment. Caribbean Fishery Management Council. San Juan, PR. 16 pp. + appendices. http://www.caribbeanfmc.com/SCANNED%20FMPS/REEF%20FISH/reef_fish_amendment__redhind.htm.

Caribbean Fishery Management Council (CFMC). 2004. Final Environmental Impact Statement for the Generic Essential Fish Habitat Amendment to: Spiny Lobster, Queen Conch, Reef Fish, and Coral Fishery Management Plans for the U.S. Caribbean, Vol. I. NOAA Award No. NA17FC1051. Caribbean Fishery Management Council. San Juan, PR. 499 pp. http://www.caribbeanfmc.com/SCANNED%20FMPS/FINAL%20EFH-EIS/EFH-EIS%20FMP.htm.

Caribbean Fishery Management Council (CFMC). 2005. Comprehensive Amendment to the Fishery Management Plans (FMPs) of the U.S. Caribbean to Address Required Provisions of the Magnuson-Stevens Fishery Conservation and Management Act. Caribbean Fishery Management Council. San Juan, PR. 624 pp. http://www.caribbeanfmc.com/SCANNED%20FMPS/06%20FINAL%20SFA%20-%20MAY%2003,2005/SFA-FMP.htm.

Ch2M Hill/CSA Group. 2006. Semiannual report for the Aguadilla RWWTP 301(h) waiver demonstration studies, November/December 2005. Technical Report. Document #: CP-AG-00079-06. Submitted to U.S. Environmental Protection Agency, Region 2. 101 pp.

Carrubba, L., E. Otero, N. Jimenez, and J. Bauzá. 2003. Using GIS to quantify propeller scarring in seagrass beds of La Parguera and Guanica Natural Reserves, Puerto Rico. Presented at Preceedings of the 31st Scientific Meeting of the Association of Marine Laboratories of the Caribbean. Port of Spain, Trinidad, West Indies.

Davis, M, E. Gladfelter, H. Lund, and M. Anderson. 1986. Geographic range and research plan for monitoring white band disease. Virgin Islands Biosphere Reserve Research Report 6. Virgin Islands Resource Management Cooperative. St. John, U.S. Virgin Islands. 28 pp.

Florida Department of Environmental Protection (FDEP). 2004. Southeast Florida coral reef initiative: a local action strategy. Coral Reef Conservation Program, Office of Coastal and Aquatic Managed Areas, Florida Department of Environmental Protection. Miami, FL. 28 pp. http://www.dep.state.fl.us/coastal/programs/coral/documents/2005/SEFCRI_LAS_FINAL_20May05.pdf.

Fonseca, M.S., W.J. Kenworthy, and G.W. Thayer. 1998. Guidelines for the conservation and restoration of seagrasses in the United States and adjacent waters. NOAA Coastal Ocean Program Decision Analysis Series No. 12. NOAA National Centers for Coastal Ocean Science. Silver Spring, MD. 222 pp.

Frias-Torres, S. 2006. Habitat use of juvenile goliath grouper *Epinephelus itajara* in the Florida Keys, USA. Endang. Species Res. 1: 1-6.

García-Sais, J.R., R. Castro, and J. Sabater. 2001a. Coral reef communities from Natural Reserves in Puerto Rico: a baseline quantitative assessment for prospective monitoring programs. Vol. 1 - Cordillera de Fajardo, Guanica, Bahia de Mayaguez, Caja de Muertos. Final Report Submitted to the Department of Natural and Environmental Resources and NOAA/U.S. Coral Reef National Monitoring Program. 232 pp.

García-Sais, J.R., R. Castro, J. Sabater, and M. Carlo. 2001b. Coral reef communities from Natural Reserves in Puerto Rico: a baseline quantitative assessment for prospective monitoring programs. Vol. 2 - La Parguera, Boqueron, Isla de Mona, Isla Desecheo. Final Report Submitted to the Department of Natural and Environmental Resources and NOAA/U.S. Coral Reef National Monitoring Program. 193 pp.

García-Sais, J.R., R. Castro, J. Sabater, and M. Carlo. 2001c. Coral reef communities from Natural Reserves in Puerto Rico: a baseline quantitative assessment for prospective monitoring programs. Vol. 3 - Guayanilla, Ponce, Guayama, Arroyo. Final Report Submitted to the Department of Natural and Environmental Resources and NOAA/U.S. Coral Reef National Monitoring Program. 147 pp.

García-Sais, J.R, R. Castro, J. Sabater, and M. Carlo. 2001d. Baseline characterization of coral reef and seagrass communities from Isla de Vieques, Puerto Rico. Final Report Submitted to the Department of Natural and Environmental Resources and NOAA/U.S. Coral Reef National Monitoring Program. 108 pp.

García-Sais, J.R., R. Appeldoorn, A. Bruckner, C. Caldow, J.D. Christensen, C. Lilyestrom, M.E. Monaco, J. Sabater, E. Williams, and E. Diaz. 2005a. The state of coral reef ecosystems of the commonwealth of Puerto Rico. pp. 91-134. In: J.E. Wadell (ed.). The state of coral reef ecosystems of the United States and Pacific Freely Associated States: 2005. NOAA Technical Memorandum NOS NCCOS 11. Silver Spring, MD. 522 pp.

García-Sais, J.R., R. Castro, J. Sabater, and M. Carlo. 2005b. Inventory and atlas of corals and coral reefs, with emphasis on deep-water coral reefs from the U.S. Caribbean EEZ (Puerto Rico and the United States Virgin Islands). Final Report submitted to the Caribbean Fishery Management Council. San Juan, PR. 215 pp.

García-Sais, J.R., R. Castro, J. Sabater-Clavell, R. Esteves, and M. Carlo. 2005c. Monitoring of coral reef communities at Isla Desecheo, Rincon, Mayaguez Bay, Guanica, Ponce and Isla Caja de Muerto, Puerto Rico, 2005. Final Report submitted to the Department of Natural and Environmental Resources of Puerto Rico. San Juan, PR. 131 pp.

García-Sais, J.R., R. Castro, J. Sabater-Clavell, R. Esteves, and M. Carlo. 2006. Monitoring of coral reef communities from natural reserves in Puerto Rico, 2006: Isla Desecheo, Rincon, Mayaguez Bay, Guanica, Ponce and Isla Caja de Muerto. Final Report submitted to the Department of Natural and Environmental Resources of Puerto Rico. San Juan, PR. 151 pp.

García-Sais, J.R., R. Castro, J. Sabater, M. Carlo, R. Esteves, and S. Williams. 2007. Monitoring of coral reef communities from natural reserves in Puerto Rico: Isla Desecheo, Rincon, Guanica, Ponce, Caja de Muerto and Mayaguez, 2006-2007. Final Report submitted to the Department of Natural and Environmental Resources of Puerto Rico. San Juan, PR. 194 pp.

Glynn, P.W., J.M. Touriño, A.C. Baker, and M.O. Calderon. 2001. Coral bleaching and mortality in Panama and Ecuador during the 1997–1998 El Niño-Southern Oscillation event: spatial/temporal patterns and comparisons with the 1982-1983 event. Bull. Mar. Sci. 69: 79-109.

GMI (Geo-Marine, Inc.). 2003. Reef ecosystem baseline assessment survey and monitoring, Vieques Island, Naval Station Roosevelt Roads, Puerto Rico. Prepared for Atlantic Division, Naval Facilities Engineering Command, U.S. Department of Navy. Norfolk, VA.

GMI (Geo-Marine Inc.). 2005. An assessment of the condition of coral reefs off the former Navy bombing ranges at Isla de Culebra and Isla de Vieques, Puerto Rico. Prepared for Legacy Resource Management Program, U.S. Department of Defense, Arlington VA, and U.S. Army Corps of Engineers, Huntsville, AL.

Hemminga, M. and C. Duarte. 2000. Seagrass Ecology. Cambridge University Press. Cambrige, UK. 298 pp.

Hernández-Delgado, E.A. University of Puerto Rico at Rio Piedras. Rio Piedras, PR. Personal communication.

Hernández-Delgado, E.A. 2003. Coral reef ecological change long term monitoring program for the Luis Peña Channel no-take Natural Reserve, Culebra, Puerto Rico (1997-2003): I. Status of the coral reef epibenthic communities. Final Report Submitted to the Department of Natural and Environmental Resources and NOAA/U.S. Coral Reef National Monitoring Program. San Juan, PR. 163 pp.

Hernández-Delgado, E.A., C,G. Toledo, H. Claudio, J. Lassus, M.A. Lucking, J. Fonseca, K. Hall, J. Rafols, H. Horta, and A.M. Sabat. 2006. Spatial and taxonomic patterns of coral bleaching and mortality in Puerto Rico during year 2005. Satellite Tools and Bleaching Response Workshop: Puerto Rico and the Virgin Islands. St. Croix, U.S. Virgin Islands. 16 pp.

Hernández-Delgado, E.A. and A.M. Sabat. In press. Long-term phase shifts in a coral reef community within a no-take natural reserve Puerto Rico. Coral Reefs.

Hoegh-Guldberg, O. 1999. Climate change, coral bleaching and the future of the world's coral reefs. Mar. Freshw. Res. 50(8): 839-866.

Hughes, T.P. 1994. Catastrophes, phase shifts and large scale degradation of a Caribbean coral reef. Science 265(5178): 1547-1549.

Juhl, R. and J.A. Suárez-Caabro. 1972. A Report on Fisheries Statistics Program in Puerto Rico from 1967 to 1972. Puerto Rico Department of Agriculture. San Juan, PR. 30 pp. http://www.sefsc.noaa.gov/sedar/download/S14RD35%20PR%20Stats%201967-72.pdf?id=DOCUMENT.

Kendall, M.S., M.E. Monaco, K.R. Buja, J.D. Christensen, C.R. Kruer, M. Finkbeiner, and R.A. Warner. 2001. Methods used to map the benthic habitats of Puerto Rico. NOAA Technical Memorandum NOS NCCOS CCMA 152 (on-line). http://ccma.nos.noaa.gov/products/biogeography/benthic/welcome.html.

Lauenstein, G.G. and A.Y. Cantillo (eds.). 1993. Sampling and analytical methods of the National Status and Trends Programs, National Benthic Surveillance and Mussel Watch Projects, 1984-1992. NOAA Tech. Memo. NOS ORCA 71, Vol 1.

LeGore, S. 2006. Puerto Rico marine ornamental fishery evaluation Phase II: Wild population assessments. Final Report to the Caribbean Coral Reef Institute, University of Puerto Rico at Mayagüez. Mayagüez, PR. 63 pp. http://ccri.uprm.edu/researcher/LeGore/PhaseIIReport.pdf.

Long, E.R., L.J. Field, and D.D. MacDonald. 1998. Predicting toxicity in marine sediments with numerical sediment quality guidelines. Environ. Toxicol. Chem. 17(4): 714-727.

Matos-Caraballo, D. Fisheries Research Laboratory, Puerto Rico Department of Natural and Environmental Resources. Mayagüez, PR. Personal communication.

Matos-Caraballo, D. 2004a. Comprehensive Census of the Marine Fishery of Puerto Rico, 2002. Commerical Fisheries Statistics Program, Fisheries Research Laboratory, Puerto Rico Department of Natural and Environmental Resources. Mayagüez, PR. 85 pp.

Matos-Caraballo, D. 2004b. PR/NMFS Cooperative Fisheries Statistics Program 2001-2004: Collection of Puerto Rico's Commercial Landings Data. Puerto Rico Department of Natural and Environmental Resources. Final Report to NOAA National Marine Fisheries Service (NMFS), Grant NA17FT1006. 49 pp.

Matos-Caraballo, D. 2005. Bycatch Study of the Puerto Rico's Marine Commercial Fisheries. Puerto Rico Department of Natural and Environmental Resources. Final Report to NOAA National Marine Fisheries Service (NMFS), Grant NA04NMF433071. 15 pp.

McClanahan, T.R. 2004. The relationship between bleaching and mortality of common corals. Mar. Biol. 144: 1239-1245.

Nemeth, R.S. 2005. Population characteristics of a recovering US Virgin Islands red hind spawning aggregation following protection. Mar. Ecol. Prog. Ser. 286: 81-97.

Nemeth, R.S., S. Herzlieb, E.S. Kadison, M. Taylor, P. Rothenberger, S. Harold, and W. Toller. 2004. Coral reef monitoring in St. Croix and St. Thomas, United States Virgin Islands. Final report submitted to U.S. Virgin Islands Department of Planning and Natural Resources. 79 pp.

Ojeda-Serrano, E., R. Appeldoorn, and I. Ruiz-Valentin. 2007. Reef fish spawning aggregations of the Puerto Rican shelf. Final Report to the Caribbean Coral Reef Institute, University of Puerto Rico at Mayagüez. Mayagüez, PR. 31 p. http://ccri.uprm.edu/researcher/Ojeda/Ojeda_Final_Report_CCRI_SPAG's.pdf.

Otero, E. and L. Carrubba. 2007. Characterization of Mechanical Damage to Seagrass Beds in La Cordillera Reefs Natural Reserve. Final Report submitted to the Puerto Rico Department of Natural and Environmental Resources.

Pait, A.S., D.R. Whitall, C.F.G. Jeffrey, C. Caldow, A.L. Mason, J.D. Christensen, Mark E. Monaco, and J. Ramirez. 2007. An Assessment of Chemical Contaminants in the Marine Sediments of Southwest Puerto Rico. NOAA Technical Memorandum NOS NCCOS 52. Silver Spring, MD. 112 pp.

PRT (Puerto Rico Tourism Co.). 2005. Selected statistics of the tourism in Puerto Rico, 2004-05 edition. Office of Research and Statistics, Commonwealth of Puerto Rico Tourism Company. 48 pp.

Richardson, L.L. and R.R. Aronson. 2002. Infectious diseases of reef corals. pp. 1225-1230. In: Moosa, M.K., S. Soemodihardjo, A. Soegiarto, K. Romimohtarto, A. Nontji, Soekarno, and Suharsono (ed.). Proceedings of the 9th International Coral Reef Symposium, Vol. 2. Bali, Indonesia. 580 pp.

Román, Ana. U.S. Fish and Wildlife Service. Boqueron, Puerto Rico. Personal Communication.

Rosario, A. 1996. Caribbean/NMFS Cooperative SEAMAP Program Annual Report: Shallow-water Reef Fish Monitoring. 133 pp.

Sadovy, Y.S., P.L. Colin, and M.L. Domeier. 1994. Aggregation and spawning in the tiger grouper, *Mycteroperca tigris* (Pisces: Serranidae). Copeia 2: 511-516.

Singh, H., R. Armstrong, F. Gilbes, R. Eustice, C. Roman, O. Pizarro, and J. Torres. 2004. Imaging coral I: Imaging coral habitats with the Seabed AUV. J. Subsurface Sensing Tech. Appl. 5(1): 25-42.

Smith, G.W., I.D. Ives, I.A. Nagelkerken, and K.B. Ritchie. 1996. Aspergillosis associated with Caribbean sea fan mortalities. Nature 382: 487.

Waddell, J.E. (ed.). 2005. The state of coral reef ecosystems of the United States and Pacific Freely Associated States: 2005. NOAA Technical Memorandum NOS NCCOS 11. Silver Spring, MD. 522 pp.

Ward, J.R., K.L. Rypien, J.F. Bruno, C.D. Harvell, E. Jordán-Dahlgren, K.M. Mullen, R.E. Rodríguez-Martíne, J. Sánchez, and G. Smith. 2006. Coral diversity and disease in Mexico. Dis. Aquat. Org. 69: 23-31.

Weil, E. 2002. Coral disease epizootiology: Status and research needs. Coral Health and Disease: Developing a National Research Plan. Coral Health and Disease Consortium. Charleston, SC. 14 pp.

Weil, E. 2004. Coral Reef Disease in the Wider Caribbean. pp. 35-64. In: E. Rosenberg and Y. Loya (eds.). Coral Health and Disease. Springer. Berlin, Heidelberg, New York. 488 pp.

Weil E., I. Urreiztieta, and J. Garzón-Ferreira. 2002. Geographic variability in the incidence of coral and octocoral diseases in the wider Caribbean. pp. 1231-1238. In: Moosa, M.K., S. Soemodihardjo, A. Soegiarto, K. Romimohtarto, A. Nontji, Soekarno, and Suharsono (ed.). Proceedings of the 9th International Coral Reef Symposium, Vol. 2. Bali, Indonesia. 580 pp.

Weil, E., E.A. Hernandez-Delgado, A. Bruckner, A. Ortiz, M. Nemeth, and H. Ruiz. 2003. Distribution and status of acroporid populations in Puerto Rico. pp. 71-92. In: A.W. Bruckner (ed.). Proceedings of the Caribbean Acropora Workshop: Potential application of the U.S. Endangered Species Act as a conservation strategy. NOAA Technical Memorandum NOAA NMFS 24. Silver Spring, MD. 199 pp.

Wusinich-Mendez, D., M. Lopez-Rivera, and E. Diaz. 2007. Puerto Rico Coral Reef MPA Summary. pp. 103-116. In: D. Wusinich-Mendez and C. Trappe (eds.). Report on the Status of Marine Protected Areas in Coral Reef Ecosystems of the United States. Volume 1: Marine Protected Areas Managed by U.S. States, Territories, and Commonwealths. NOAA Technical Memorandum CRCP 2. Silver Spring, MD. 129 pp.

# The State of Coral Reef Ecosystems of Navassa Island

Margaret W. Miller[1], A. Gleason[2], D. McClellan[1], G. Piniak[4], D. Williams[1,2], J.W. Wiener[6], A. Gude[3], J. Schwagerl[5]

## INTRODUCTION AND SETTING

Navassa is a small (4.64 km$^2$), uninhabited, oceanic island approximately 50 km off the southwest tip of Haiti (Figure 4.1) under the jurisdiction of the U.S. Fish and Wildlife Service. The island is a raised dolomite plateau ringed by vertical cliffs that descend to a sloping submarine terrace at an approximate depth of 25 m, with coral reef development primarily on small nearshore ledges and shelves. Navassa's oceanic position in the Windward Passage exposes it to substantial physical energy, with the eastern coastline exposed to persistent swells and regular storms and hurricanes. Both geomorphology and exposure have resulted in an absence of shallow-water inshore fish nursery habitats (e.g., mangroves, sandy beaches and seagrasses) that are found on other islands in the region. The local and regional oceanography around Navassa is poorly characterized, but detailed geology is provided in Miller et al. (in press).

Status of reef resources and threats have been documented by Miller and Gerstner (2002), Miller (2003) and Miller et al. (2005) from data collected during expeditions in 2000 and 2002. These assessments reported relatively healthy coral conditions and reef fish assemblages which, though dominated by small planktivores, still compared favorably with other Caribbean locations. Substantial fishing activity by transient Haitians was also reported.

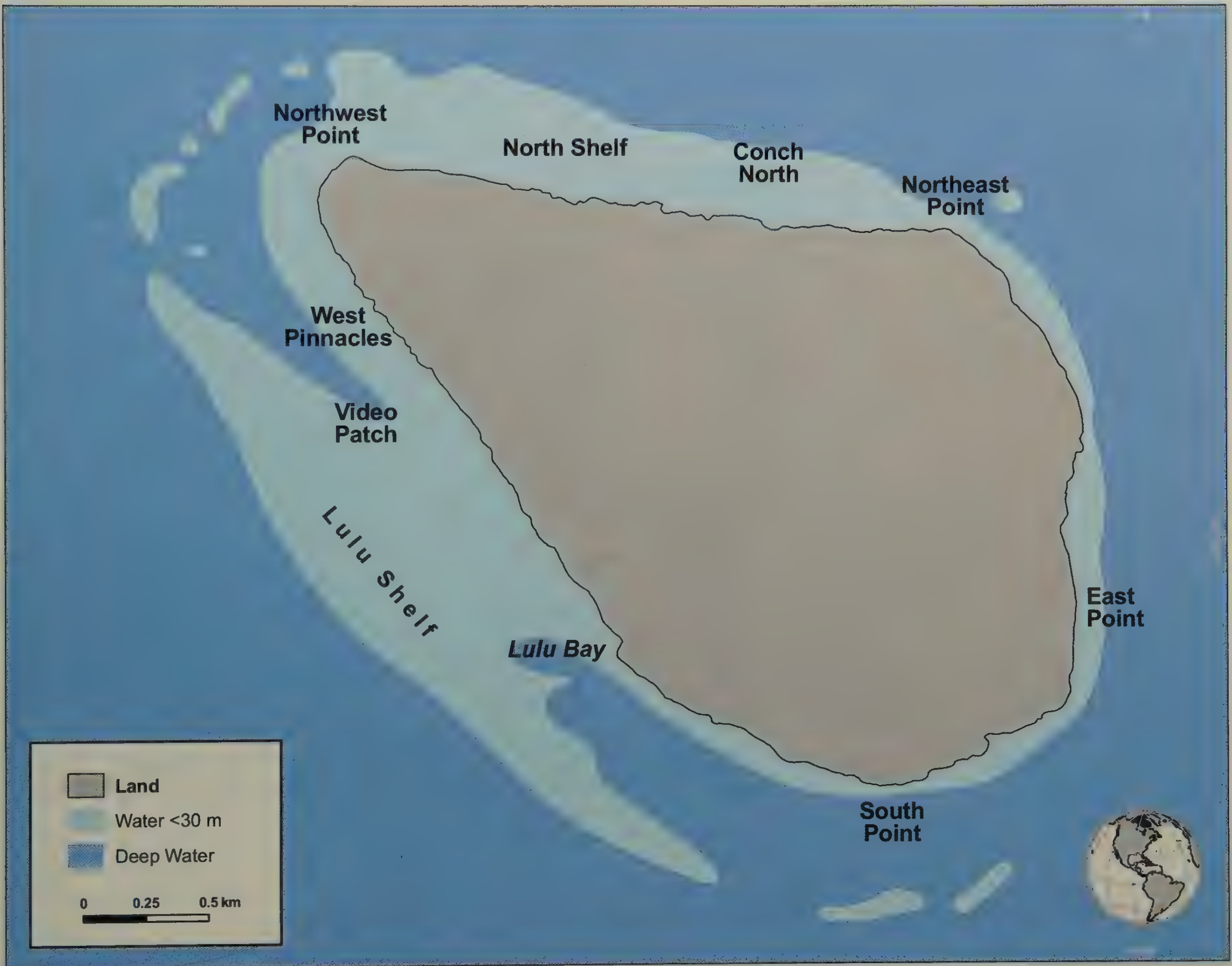


*Figure 4.1. A map of Navassa Island showing locations mentioned in the chapter. Map: K. Buja.*

---

1 NOAA Fisheries, Southeast Fisheries Science Center
2 University of Miami, Rosenstiel School for Marine and Atmospheric Sciences
3 U.S. Fish and Wildlife Service, National Wildlife Refuge System Headquarters
4 NOAA-NOS, Center for Coastal Fisheries and Habitat Research
5 U.S. Fish and Wildlife Service, Caribbean Islands National Wildlife Refuge, Boqueron, Puerto Rico
6 Fondation pour la Protection de la Biodiversité Marine, Port-au-Prince, Haiti

## ENVIRONMENTAL AND ANTHROPOGENIC STRESSORS

### Climate Change and Coral Bleaching

No suitable historic observations are available to determine past occurrence or potential trends in coral bleaching at Navassa, particularly through the 2005 Caribbean event. Observations in April 2006 indicated that bleaching was not extensive (G. Piniak, pers. obs.). Miller et al. (2005) suggested that the relatively deep and exposed (i.e., high water flow) position of most of the coral reefs surrounding Navassa reduced exposure to elevated sea surface temperatures (SST). However extensive, and in some places, severe coral bleaching was observed at Navassa in November 2006, when little new bleaching had been reported in the Caribbean and no predictions of bleaching (bleaching alerts) had been issued based on satellite temperature records. In fact, observed bleaching prevalence was greater at deep sites (20-30 m) than at shallow (7-10 m) sites. *In situ* temperature data was collected at a range of depths around Navassa from April to November 2006 providing potentially useful data that can contribute to the future development of accurate bleaching predictions for corals in deeper water (20-30 m). Please see the Water Quality and Benthic Habitats sections of this chapter for more information on elevated SST and coral bleaching.

### Diseases

Until 2004, coral diseases at Navassa were rarely seen (Miller et al., 2005). During the November 2004 expedition, however, a severe coral disease event was observed (Miller and Williams, 2007; see Benthic Habitat section). This disease event appeared to have developed following hurricanes Charley and Ivan that affected Navassa in 2004. No sampling for pathogen identification was possible, but disease signs were consistent with a white-plague type disease. Isolated observations of disease on *Acropora palmata* (low prevalence) and *A. cervicornis* (much higher prevalence given this species' rarity at Navassa) were also made (Williams and Miller, pers. obs.)

### Tropical Storms

Several named storms have passed near Navassa in recent years (Figure 4.2), including Ernesto (2006), Dennis (2005), Charley (2004), and Ivan (2004). Unfortunately, the wide spacing of observations makes it difficult to attribute observed reef changes directly to storms. However, following Charley and Ivan in 2004, some obvious physical damage (e.g., toppled hard and soft coral colonies) and sand movement was observed.

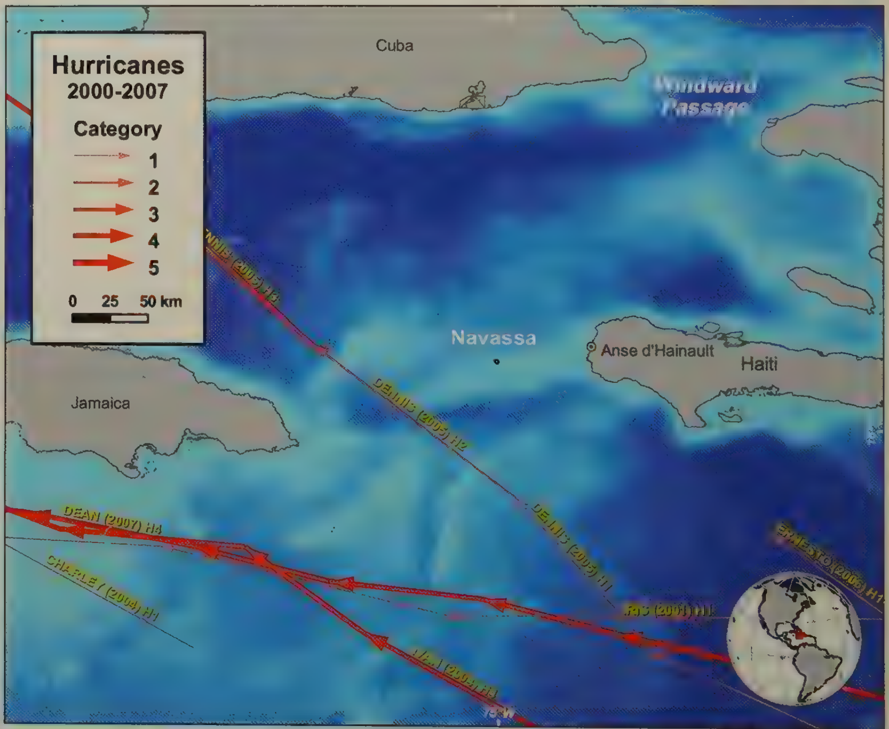


Figure 4.2. Map of Navassa Island showing the path and intensity of major storm events between 2002-2007. Map: K. Buja. Source: http://maps.csc.noaa.gov/hurricanes/.

### Coastal Development and Runoff

Navassa is uninhabited, except for the temporary presence of transient Haitian fishers. There has been no change in terrestrial activity.

### Coastal Pollution

No information about coastal pollution sources from neighboring islands that have the potential to impact Navassa is available.

### Tourism and Recreation

There is no tourism or recreational use at Navassa. A Special Use permit from the U.S. Fish and Wildlife Service is required for entry.

### Fishing

Despite its status as a National Wildlife Refuge, fisheries at Navassa are effectively unmanaged as regulations are not well publicized and enforcement is not feasible in this remote location. Fishing activities by migrant Haitian artisanal fishermen have been ongoing since at least the 1970s. Miller et al. (2007) perceived an escalation of fishing effort based on observation of the use of novel and more destructive gear types including net fishing (first observed in 2002), which allowed exploitation and bycatch of previously unexploited species such as queen conch (*Strombus gigas*) and Hawksbill sea turtles (*Eretmochelys imbricata*; Wiener, 2005).

The National Oceanic and Atmospheric Administration's (NOAA) Southeast Fishery Science Center (SEFSC) has recently conducted a sociocultural characterization of Haitian fishing communities that exploit the waters surrounding Navassa (Wiener, 2005; Miller et al., 2007). This study included extensive interviews of fishers both on site in Navassa and in southwest Haiti, as well as limited quantification of landings from three individual boat-trips. Results of the fisher interviews conducted between November 2004 and June 2005 also indicated that capital for boats, traps and fuel was the primary limitation on current fishing effort. Similarly, the harsh living conditions on Navassa were the only factor preventing permanent settlement of the islands as socioeconomic conditions in Haiti continue to be dismal.

Unexpectedly, the most recent observations in April and November of 2006 revealed a reduction in fishing activity when compared with 2004. A total of 175 fixed gear buoys (marking an unknown ratio of traps and nets combined) were mapped in 2004 (Miller et al., 2007), whereas many fewer traps were being actively fished in April and November 2006 (Table 4.1). Other measures of fishing effort appear to have peaked in 2004 and abated in 2006. Particularly notable was the lack of net fishing in 2006. All of the fishers present in 2006 were from a single Haitian village, Anse d'Hainault, and those interviewed indicated that this village had not previously participated in net fishing. It is not clear if this apparent relaxation of fishing effort has resulted from a form of self-management, poorer yields (interviewees indicated that the fishing was very poor in 2006) or other external factors such as high fuel prices.

*Table 4.1. Trends in apparent fishing effort by transient Haitians on the Navassa shelf. Source: Miller et al., 2004; Wiener, 2005; Piniak et al., 2006.*

| MEASURE OF FISHING EFFORT | | | | | GEAR IN USE | | |
|---|---|---|---|---|---|---|---|
| Date of observation | Duration of observation (d) | Total # gear buoys/traps | Mean boats/day | Mean fishers/day | Traps | Hook and Line | Nets |
| November 2002 | 11 | NA | 2 | 9.7* | X | X | X |
| November 2004 | 13 | 175 | 4.4 | 22 | X | X | X |
| April 2006 | 10 | 7 | 0.7 | 2.8 | X | X | - |
| November 2006 | 11 | 34 | 4 | 15.9 | X | X | - |
| * Observations in 2002 were less complete; data are extrapolations based on reported average of five fishers per boat. | | | | | | | |

Additionally, Haitian commercial fishing operations and international trawlers purportedly from the Dominican Republic and Jamaica are suspected of targeting pelagic fish species within the Navassa National Wildlife Refuge's (NNWR) 12 nautical mile territorial sea.

### Trade in Coral and Live Reef Species

This threat does not have a major impact on Navassa's reefs.

### Ships, Boats and Groundings

This threat does not have a major impact on Navassa's reefs.

### Marine Debris

Marine debris from recent fishing activities and historical uses was described by Miller et al. (2005).

### Aquatic Invasive Species

Invasive species have not been observed at Navassa to date.

### Security Training Activities

No military activities occur at Navassa.

### Offshore Oil and Gas Exploration

No oil and gas exploration activities occur at Navassa.

## CORAL REEF ECOSYSTEMS—DATA-GATHERING ACTIVITIES AND RESOURCE CONDITION

Monitoring of the coral reefs of Navassa is now conducted biennially by NOAA-Fisheries and partners, with support from the NOAA Coral Reef Conservation Program. Cruises took place in November 2002, 2004 and 2006 to conduct underwater visual censuses of fish, habitat mapping (including single-beam acoustics), and benthic community assessments. Complementary data sets including multibeam bathymetry, temperature records, additional habitat assessments and sampling for trophic analysis via stable isotopes (Piniak et al., 2006) were obtained during an additional cruise in April 2006 conducted by NOAA's National Centers for Coastal Ocean Science (NCCOS), Center for Coastal Fisheries and Habitat Research (CCFHR). Monitoring locations for both groups are shown in Figure 4.3.

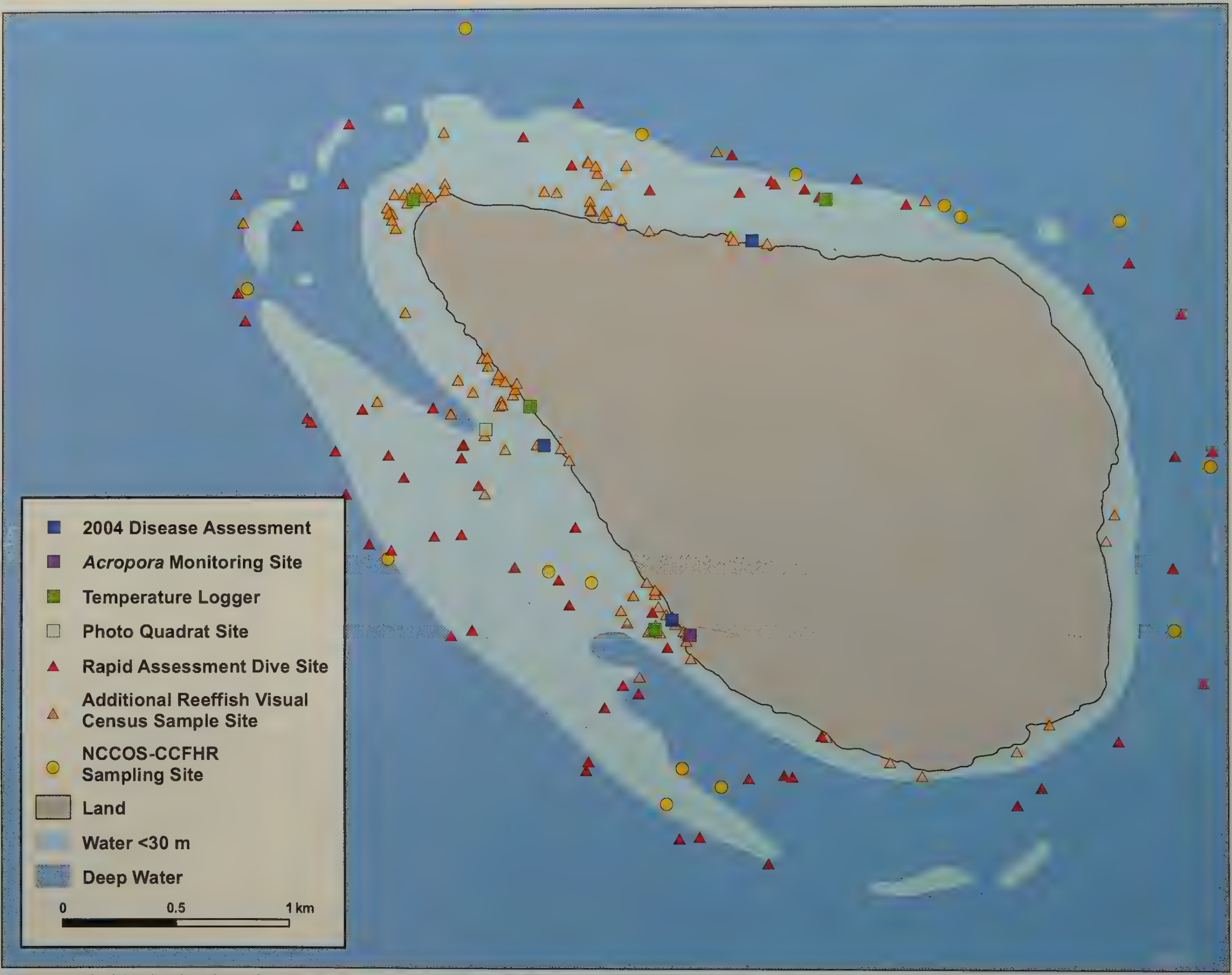

■ 2004 Disease Assessment
■ *Acropora* Monitoring Site
■ Temperature Logger
□ Photo Quadrat Site
▲ Rapid Assessment Dive Site
△ Additional Reeffish Visual Census Sample Site
○ NCCOS-CCFHR Sampling Site
▭ Land
Water <30 m
Deep Water
0
0.5
1 km

Figure 4.3. Monitoring locations sampled by NOAA/SEFSC and NOAA/NCCOS. Map: K. Buja.

## WATER QUALITY AND OCEANOGRAPHIC CONDITIONS

Since April 2006, temperature has been regularly measured at Navassa using an array of temperature loggers deployed at five sites at depths between 11 and 28 m. Hourly data was retrieved from these sensors in November 2006 and is summarized in Figure 4.4. Currently, temperature is the only water quality parameter being measured at Navassa.

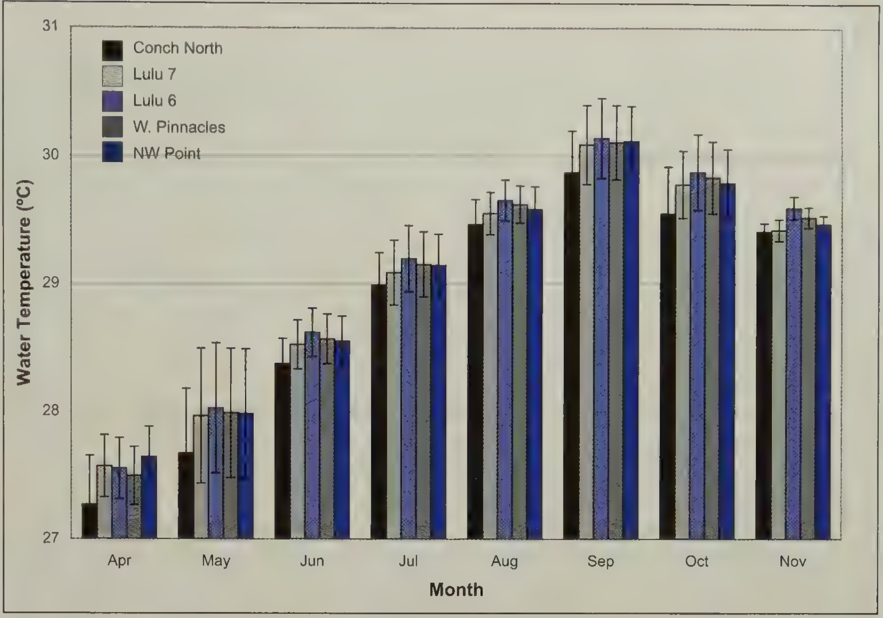


*Figure 4.4. Monthly mean (± 1 SD) of hourly temperature readings from five sites around Navassa in 2006. Sites are: Conch North (28 m depth), Lulu Bay 7 (15 m depth), Lulu Bay 6 (26 m depth), West Pinnacles (26 m depth), and Northwest Point (11 m depth). This period of time preceded the observation of a severe coral bleaching event at Navassa in November 2006. Source: Piniak et al., unpub. data.*

## BENTHIC HABITATS

### *Benthic Characterization (SEFSC 2002–2006)*

*Methods*

Given the relatively deep depths and limited sampling effort available for reef assessment at Navassa (about 10 days every two years), a hybrid sampling approach has been adopted. Standard *in situ* line intercept transects (15 m transect, sampled at 15 cm intervals, n=2-4) were used to estimate the percent cover of primary community components (scleractinian corals, macroalgae, octocorals, sponges) at four, relatively shallow (7-22 m) fixed sites every two years. Additionally, haphazard photoquadrats were collected from a distinct set of Rapid Assessment Dive (RAD) sites (22-32 m depth) distributed throughout the shelf. Photoquadrats (n=4-10) were analyzed using a standard point count method applied by Coral Point Count (CPCe) software. To enhance comparability between years, data are presented only for reef RAD sites along the southwest portion of the shelf.

*Results and Discussion*

Mean percent cover of fixed sites and deeper RAD sites are shown in Figures 4.5 and 4.6. Macroalgae (predominantly *Lobophora variegata*) comprised the dominant benthic group overall, with values around 40% cover common and values over 70% observed on occasion (Figures 4.5 and 4.6; mean ±1 SD for 2006 fixed sites, 54.4 ±17.3% SD). Declines in coral cover have occurred, but only at deeper sites (i.e., Video Patch and RAD sites) where coral cover had initially been very high and both 2004 disease and 2006 bleaching were observed at greater prevalence. Mean coral cover ±1 SD for southwest shelf RAD sites in 2002 was 39.9 ±8.0% SD but had dropped to 11.1 ±6.4% SD by 2006 (Figure 4.6). Meanwhile, live coral cover at the shallow fixed sites at NW Point and Lulu Bay have remained fairly steady in the range of 10-15% and 20-25%, respectively (Figure 4.5). Coral cover losses observed through 2006 likely resulted from disease and hurricane impacts (particularly during 2004). Ongoing coral mortality is anticipated given the severe bleaching status of corals observed in 2006.

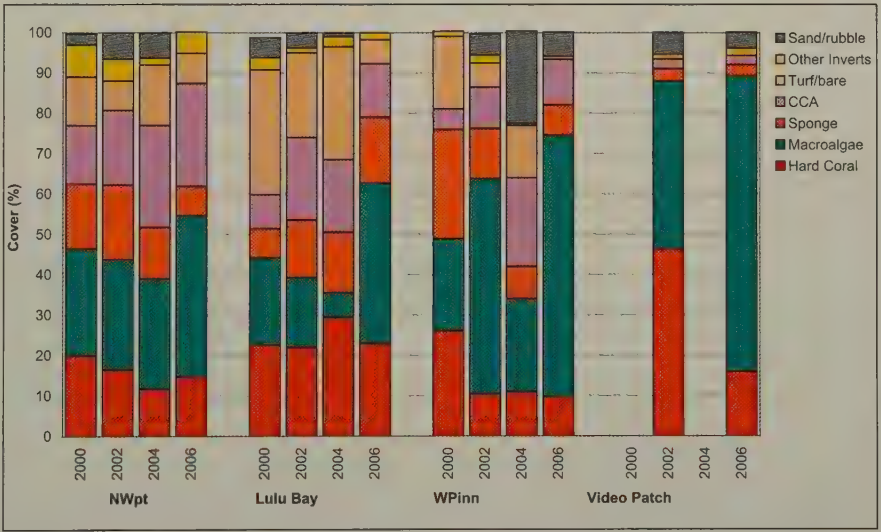


*Figure 4.5. Percent cover of fixed sites sampled via* in situ *point-intercept transects over time. NW Point, approximately 10 m; Lulu Bay: 7-10 m; West Pinnacles, 22 m; Video Patch: approximately 30 m, not sampled in 2000 or 2004. Source: Miller and Gerstner, 2002; Miller et al., 2003; Miller et al., unpub. data.*

## Benthic Characterization (NCCOS 2006)

*Methods*

The habitat characterizations on the April 2006 cruise focused on the deeper portions of the inner shelf (30-34 m). Sites were randomly selected from the appropriate depth range; each site consisted of three replicate transects deployed in random directions. A site therefore incorporated a mixture of habitat types (both reef and non-reef). Due to differences in techniques, these data are not strictly comparable to the SEFSC data. Three 30 m visual fish transects were conducted at each site (data not reported) and benthic photoquadrats were collected at each meter along the transect and analyzed using standard point count methods within CPCe software.

*Results and Discussion*

Mean percent cover for the NCCOS sites are given in Figure 4.7. Macroalgae were the dominant benthic biota, comprising 36% of the total benthic cover around Navassa. *Lobophora variegata* was by far the most abundant macroalga (maximum 34%). *Halimeda* sp. and *Dictyota* sp. were secondary components of the algal community. Coral cover ranged from 1-7%; this underestimates typical cover measurements because mixed habitat types (including non-reef areas) were surveyed at each site. The primary components of the coral communities were the species that make up the *Montastraea annularis* species complex (referred to as *Montastraea* spp.), *Siderastrea siderea*, *Porites astreoides* and *P. porites*. Coral cover was lowest on the eastern coast, which had high proportions of rock (36%) and rubble (15%); uncolonized substrate on the north and south coasts was primarily sand.

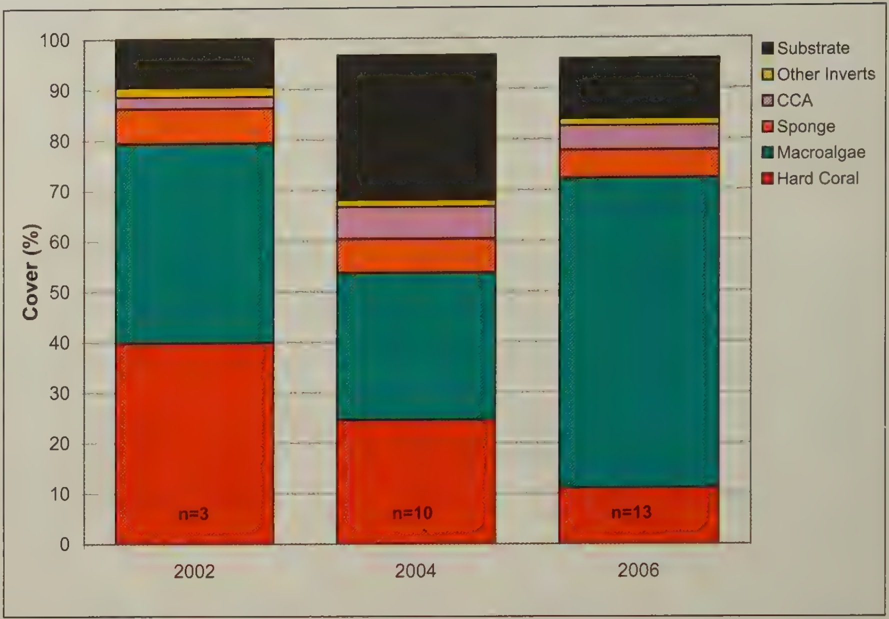


*Figure 4.6. Percent cover of southwest coast reef RAD sites (haphazardly selected each year) as determined from point counts of haphazardly-placed 1 $m^2$ photoquadrats (4-10 photoquadrats per site). Algal turfs are poorly resolved from photographs so they are included with pavement, rubble, and sand called "substrate". N given in each bar represents the number of sites (southwest patch reefs only) sampled in that year. Source: Miller et al., 2003 and Miller et al., unpub. data.*

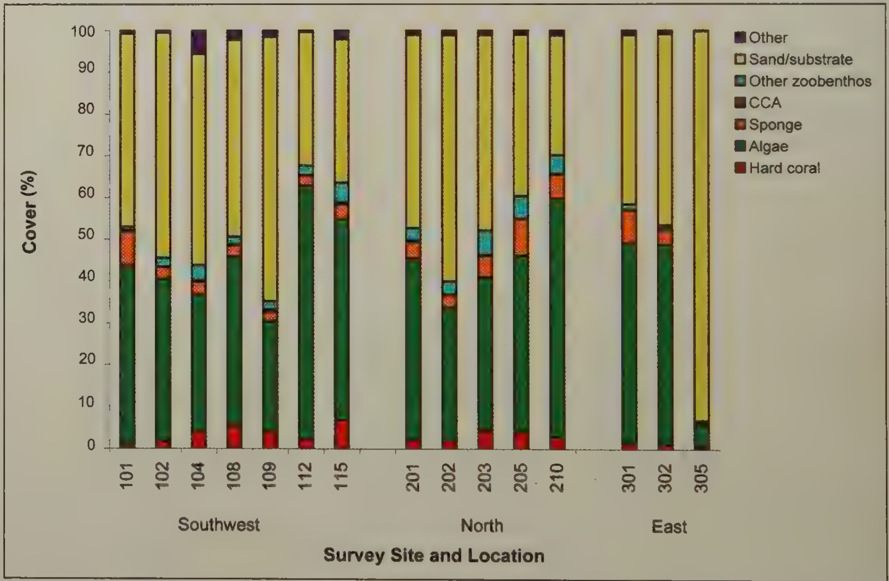


*Figure 4.7. Community composition characteristics for all sites surveyed at Navassa by NCCOS in April 2006. All sites were surveyed in situ using benthic photo transects (n=31 photos per 30 m transect, n=3 transects per site). Sites (numbers along the x-axis) were all 30-34 m depth and stratified by location (southwest, north or east coasts). Benthic cover types are grouped by NOAA Fisheries categories, but are not strictly comparable due to differences in methodology. Source: Piniak et al., in prep.*

## *Disease Characterization (SEFSC–2004)*

*Methods*

Haphazardly placed transects (n=3-7) were sampled at five sites around the island to examine spatial variation in disease prevalence upon observation of high coral disease occurrence in November 2004. Transect size was either 1 x 7.5 m or 0.5 x 10 m. Each colony within the transect was scored for species, size category (small <15 cm diameter; medium 15-40 cm; large >40 cm) and disease state was scored as either "active" disease signs, "recent mortality" or unaffected. Prevalence of both active and recently diseased states were expressed as proportion of total colonies in each disease state. Prevalence was also calculated for certain subsets of colonies, namely large colonies (>40 cm), and *Montastraea* spp. for comparison to the coral community as a whole. Further detail on the methodology employed can be found in Miller and Williams (2007).

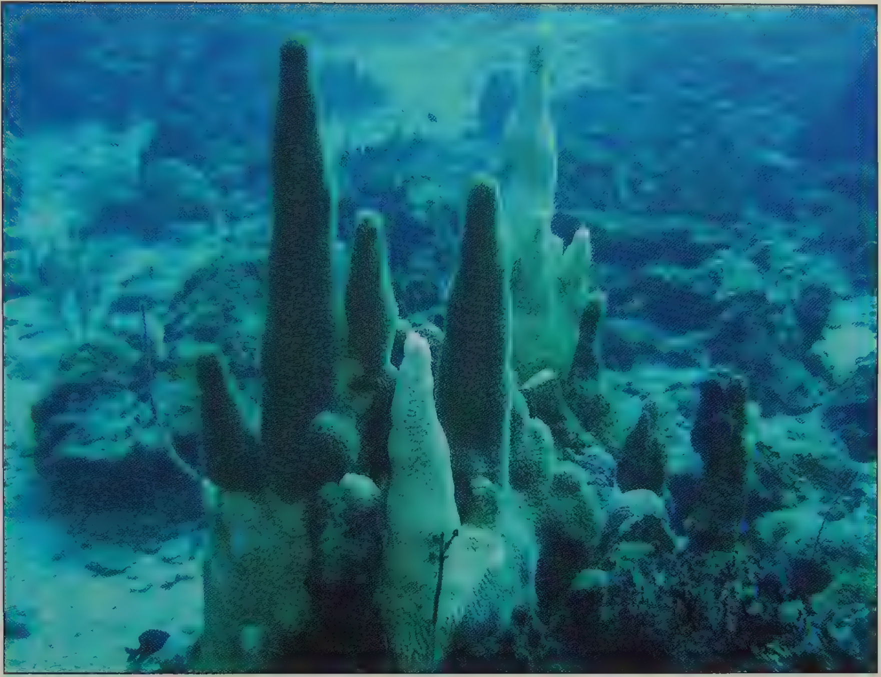


*Figure 4.8. Photo of pillar coral,* Dendrogyra cylindrical, *suffering rapid tissue loss consistent with white-plague type disease in November 2004. White areas of the colony are recently dead (skeleton); only the gray areas still have live tissue. Photo: NOAA SEFSC.*

*Results and Discussion*

Over 15 species of scleractinians were observed with "white disease" signs (Miller and Williams, 2007; Figure 4.8). Total prevalence (percent) of colonies with active disease signs at the sites sampled via haphazard transects ranged from zero at NW Point to over 15% at site A, with an additional 20% of colonies at that site displaying recent mortality (Table 4.2). Disease prevalence was substantially higher among large colonies and among *Montastraea* spp. colonies, with a majority of *Montastraea* spp. colonies affected by disease at one site (Table 4.2). The ensuing loss of large colonies is expected to affect coral community structure over a long time span.

*Table 4.2. Prevalence of active disease signs and recent mortality consistent with disease. Replicate transects were pooled from each site to indicate prevalence amongst all colonies compared to large colonies and* Montastraea *spp. colonies. No colony size information was collected at Site A. Locations are given in Figure 1. Source: Miller and Williams, 2007.*

| SITE | TOTAL COLONIES | | | COLONIES >40 cm DIAMETER | | | ***MONTASTRAEA* spp. COLONIES** | | |
|---|---|---|---|---|---|---|---|---|---|
| | N | % active disease | % recent mortality | N | % active disease | % recent mortality | N | % active disease | % recent mortality |
| A | 79 | 15 | 19 | NA | NA | NA | 19 | 36.8 | 21.1 |
| B | 360 | 6.9 | 7 | 22 | 31.8 | 0 | 44 | 25 | 2.3 |
| Video Patch | 267 | 3.4 | 2.6 | 64 | 14 | 10.9 | 28 | 21.4 | 7.1 |
| NW Pt | 137 | 0 | 0 | 6 | 0 | 0 | 5 | 0 | 0 |
| C | 300 | 1.5 | 0 | 10 | 10 | 0 | 20 | 0 | 0 |

## Bleaching Characterization (SEFSC–2006)

### Methods

A widespread and fairly severe coral bleaching event was encountered during the November 2006 cruise. Several rapid assessment techniques were utilized to document the extent (spatial patterns, species affected and severity) of coral bleaching at Navassa. Using a belt transect (10 x 1 m) at seven sites ranging in depth from 7-27 m, all colonies greater than 4 cm diameter were identified to species or genus and colonies were ranked by size class and degree of bleaching (normal, pale, mottled or completely bleached white). These categories were subsequently pooled for the current presentation. Between two and six transects were sampled at each of the seven sites.

In order to get a more representative view, scientists also performed RADs at an additional eight sites ranging in depth from 27-37 m. In these cases, no transect was laid out and a subset of common hermatypic coral species (limited to *Diploria strigosa*, *D. labyrinthiformes*, *Montastraea cavernosa*, *M. faveolata*, *M. annularis*, *M. franksi* and *Colpophillia natans*) were scored for bleaching state as described above. A haphazard compass heading and a 1 m length PVC pole was used to delineate an area for sampling. Although the total area sampled (hence colony density) cannot be determined from this data set, the use of the heading and a 1 m guide minimized bias in 'choosing' colonies to record. Bleaching prevalence (percent of colonies affected) for the sampled species was recorded.

### Results and Discussion

Overall prevalence of coral bleaching at the various sites ranged from approximately 15-78% of colonies when all species were pooled (Figure 4.9). Shallow sites (<10 m) were less affected than deeper sites (>20 m) and fringes of bleached colonies that were overgrown by macroalgae (commonly *Lobophora variegata*) were normally pigmented. This suggests that the interaction between the severity of bleaching and differences in light levels may be complex. The most impacted coral taxa were *Agaricia* spp. and *Montastraea spp.*(*M. faveolata* was greatly dominant in this group). *Siderastraea siderea*, *Diploria* spp. (predominantly *D. strigosa*) and *Porites porites* were intermediately affected. Least impacted were *P. astreoides* and *M. cavernosa*.

Qualitatively, the intensity of bleaching appeared to increase over the 11 days of observation. Some bleached colonies were clearly undergoing partial mortality, but it was not possible to differentiate causality related to bleaching versus disease as both often co-occurred in colonies (Figure 4.10).

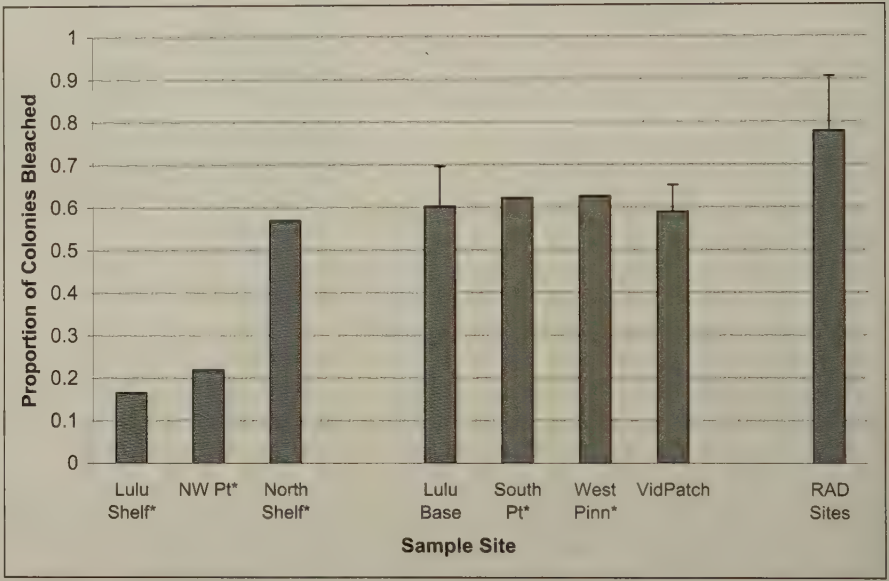


*Figure 4.9. Mean plus ±1 SD bleaching prevalence. Sites with asterisks show no variance estimate since only two transects were sampled. The error bars shown for the other sites indicated ±1 SD for n=5 or 6 transects (or six sites for RAD sites). These means pool all degrees of coral bleaching and all species sampled (see text for details). The first three sites are shallow shelf habitats (7-10 m depth). The second set of four sites range from 20-27 m depth. The last bar (RAD sites) is the mean of prevalence scored for a subset of coral species in one rapid assessment dive at each of six sites ranging from 27-37 m. Source: Miller and Williams, unpub. data.*

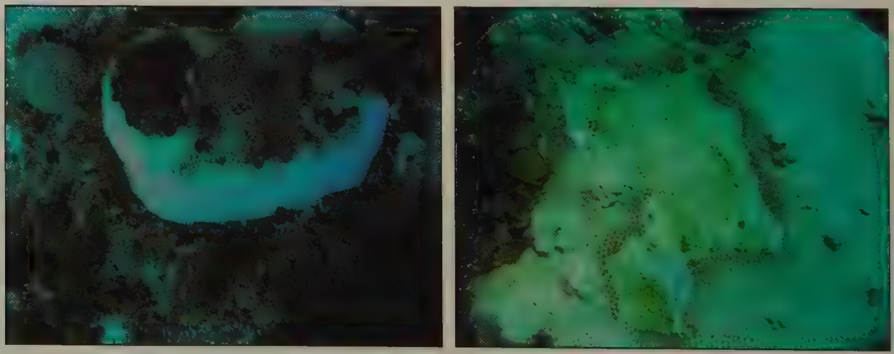


*Figure 4.10. Photos showing bleached coral with partial mortality. Left: Bleached* Siderastraea siderea *that appears to have endured multiple recent (estimated 6-18 months) partial mortality events. Note small unbleached conspecific to the left. Right: Moderately bleached* Montastraea spp. *with current mortality possibly from simultaneous disease. Photos: NOAA SEFSC.*

## *Status of Acroporids (SEFSC–2002-2006)*

*Methods*

*A. palmata* habitat is mostly confined to the shallow shelf areas around Lulu Bay and Northwest Point and around the cliff along much of the southwest and north coasts. Only qualitative observations on *Acropora* spp. abundance were made in 2002. In 2004, minimal surveys were made along confined sections of the coast. However, in 2006, following the Endangered Species Act listing of these species, targeted abundance sampling and demographic monitoring were established. We quantified the spatial extent and location of *A. palmata* colonies along the entire north and southwest coasts using snorkeler observations and a handheld Global Positioning System to mark the position of each colony encountered. Approximately 6.8 km of the estimated 9 km of coastline was surveyed for *A. palmata*. In addition, a total of 77 *A. palmata* colonies in five permanently marked plots (three around Northwest Point and two near Lulu Bay) were tagged, assessed, photographed, and biopsied for genotyping according to protocols developed and applied in the Florida Keys (Williams et al., 2006). Future surveys will reveal the recruitment and survivorship of the population at Navassa.

*Results and Discussion*

In stark contrast to other coral species in the area, the majority of *A. palmata* colonies observed appeared healthy with recent mortality observed only occasionally. A total of 1,800 colonies were mapped over 6.8 km of the Navassa coast. Although rough seas prevented surveys along the east coast of the island, heavy swells along this windward coast seem to limit coral development, and few *Acropora* spp. colonies were expected to occur in this area. In contrast, the 1998 expedition to the island (Littler et al., 1999) reported approximately one dozen *A. palmata* colonies confined to Lulu Bay based on casual observation. While targeted surveys of *A. palmata* were not conducted in 1998, it appears that the population has increased, with our 2006 survey counting more than 100 colonies in Lulu bay, and observations of portions of the wall that were paved with encrusting *A. palmata*.

In contrast to *A. palmata*, *A. cervicornis* remains extremely rare at Navassa. A total of only five small colonies were observed in over 250 person dives during the November 2006 cruise. One of these colonies clearly displayed tissue sloughing, a sign of disease, as has been observed in the Florida Keys (Williams and Miller, 2005).

## *Mapping*

Directed efforts at mapping Navassa's benthic habitats began in 2004 with single beam acoustic work and benthic community characterization by scientists from the University of Miami's Rosenstiel School of Marine and Atmospheric Science (RSMAS). Multibeam mapping of the Navassa shelf was conducted in April 2006 by NCCOS-CCFHR in partnership with Solmar Hydro from approximately the 20 m contour out to 12 nm (about 22 km) from the island. A digital elevation model based on Light Detection and Ranging (LiDAR) data acquired in 1999 and multibeam bathymetry was used to calculate slope. Figure 4.11 shows the result when these two output layers were combined.

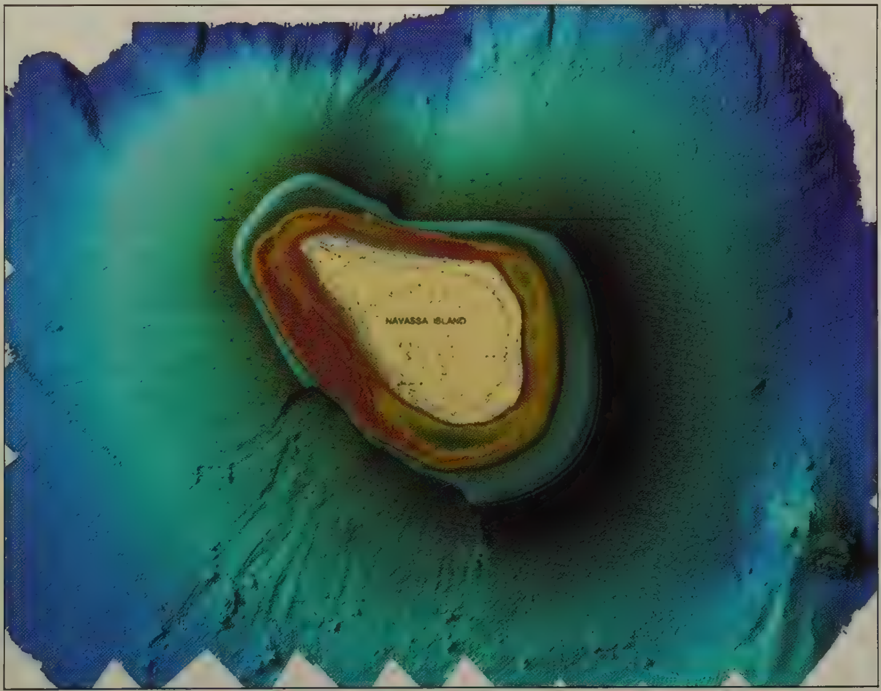


*Figure 4.11. Bathymetric map of Navassa Island and the surrounding coastal area. Source data: Solmar Hydro and NASA.*

Results of a slope calculation performed using multibeam data from 20–50 m depths with the Matlab Mapping Toolbox (Version 1.2; Mathworks, Natick, MA), which uses finite differences to compute the gradient of a gridded data set are shown in Figure 4.12A. Single beam acoustic data were acquired as points along track lines, classified, then gridded to 100 m cells using a majority filter. Figure 4.12B shows the acoustic seabed classification based on the percent of the seabed covered with sediment (patchiness) and the local variability in depth (relief). Information from all sources (IKONOS satellite imagery, multibeam bathymetry, benthic community analysis, drop camera and diver observation) were integrated into the habitat map (Figure 4.12C). Details of map construction are given in Miller et al. (in review).

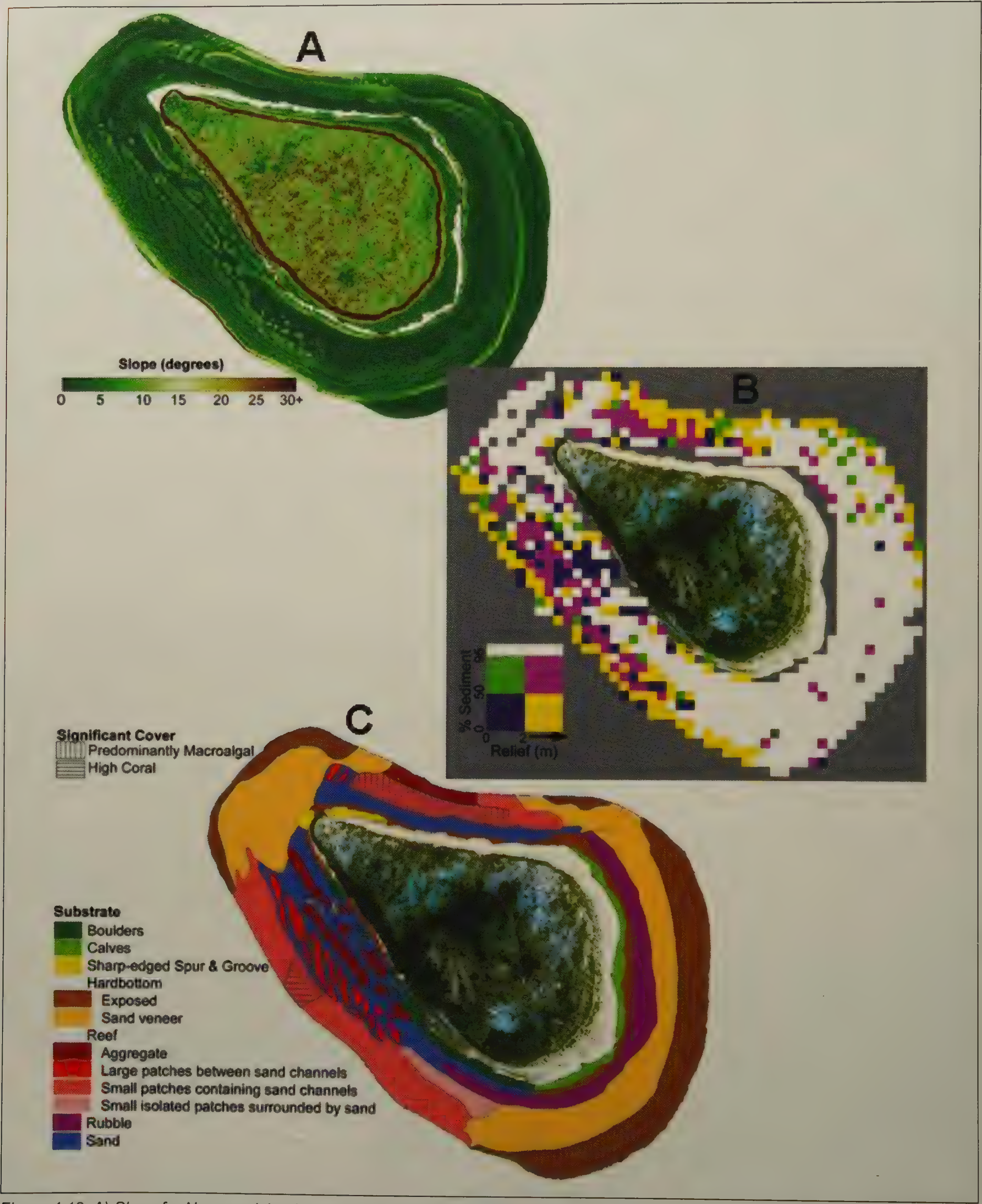

A
Slope (degrees)
0
5
10
15
20
25
30+
B
% Sediment
0
50
100
0
2
Relief (m)
C
Significant Cover
Predominantly Macroalgal
High Coral
Substrate
Boulders
Calves
Sharp-edged Spur & Groove
Hardbottom
Exposed
Sand veneer
Reef
Aggregate
Large patches between sand channels
Small patches containing sand channels
Small isolated patches surrounded by sand
Rubble
Sand

*Figure 4.12. A) Slope for Navassa Island computed from NASA's LiDAR data on land and Simrad XX data from 20-50 m water depth. Values above 30 degrees were clipped to show detail in the range 0-30 degrees. Maximum slope for this data set was 80 degrees. Null values due to lack of data are shown in white encircling the island. B) Acoustic seabed classification based on "patchiness", the percent of the seabed covered with sediment, and "relief", the local variability in depth. Data were acquired as points along track lines, classified, then gridded to 100 m cells using a majority filter. No data is shown as gray. C) Interpreted benthic habitat map based on all available information sources including bathymetry, IKONOS imagery, benthic community classification, and diver/drop camera observations. Sources: A) Solmar Hydro, NASA; B and C) A.Gleason, Univ. of Miami/RSMAS.*

# ASSOCIATED BIOLOGICAL COMMUNITIES

## *Fish Surveys (SEFSC)*

Data on reef fish assemblages and other mobile fauna have been collected via a stationary point sampling technique (Bohnsack and Bannerot, 1986; McClellan and Miller, 2003) referred to as Reeffish Visual Census (RVC). The total number of samples and summary results are given in Table 4.3. Sites sampled in 2006 included both stratified random sites (according to habitat map in Figure 4.12C) and targeted RAD sites. In addition to enumerating reef fishes, RVC samples record the presence and abundance of selected mobile macroinvertebrates, including the long-spined sea urchin (*Diadema antillarum)*, queen conch (*Strombas gigas*) and lobster (*Panulirus argus*, not reported here). The abundance of *D. antillarum*, an important grazer, was also noted in benthic transect sampling at fixed sites surveyed by the SEFSC in 2006.

### *Results and Discussion*

There is a clear declining trend in reef fish biomass (Figure 4.13 and Table 4.3) between 2002 and 2006 as determined by the RVC sampling. This trend is most evident in piscivores, herbivores and planktivores (the dominant trophic groups in terms of biomass). Macroinvertivores were the only group which showed a substantial increase in 2006 but this increase was due to squirrelfish only (data not shown), a common family which are preyed upon by piscivores as well as Navassa's human fishers. Fish sizes (mean fork length of individuals >10 cm) also showed a significant decline between 2002 and 2004 for grouper, snapper, triggerfish, parrotfish, jack, surgeonfish and squirrelfish families (Miller et al., 2007).

It should be noted that a more restricted set of habitats was sampled in 2002, particularly high-relief habitats near shore such as wall and wall base/boulder habitats. However, the same declining temporal trends are evident if relatively depauperate, non-reef habitats (e.g., sand/rubble) are excluded from the latter years' samples (data not shown). Hence, it is not likely that the observed decline in fish biomass (Table 4.3) can be explained by differential habitat representation.

On the other hand, abundance of *D. antillarum* has increased over the four year interval. The mean density of urchins from the RVC data (number/sample) increased 400% between 2002 and 2006 (Table 4.3). Benthic transects indicated a November 2006 *D. antillarum* density of 0.16 $m^2$ + 0.02 % SE (n=11 10 $m^2$ transects among six sites). Although these densities are nowhere near those that have been shown to correspond with enhanced coral recruitment (i.e., 2-5 per $m^2$; Carpenter and Edmunds, 2006)], densities are likely approaching this level in certain habitats (e.g., nearshore boulder/calves habitat on night dive; M. Miller, pers. obs.). The marked increase suggests that recovery of *Diadema* populations is underway at Navassa. Conch are known to be highly aggregative and we observed no clear temporal trend in their abundance (Table 4.3). RVC samples in 2004 encountered several conch aggregations and this yielded higher mean and frequency of occurrence estimates in 2004 (Table 4.3).

*Table 4.3. Summary of RVC data, including relative abundance of conch and urchins (D. antillarum) collected in 2002, 2004 and 2006. Sampling intensity has increased slightly over the study, including a wider range of habitats. Source: McClellan and Miller, 2003; McClellan et al., unpub. data.*

| | **2002** | **2004** | **2006** |
|---|---|---|---|
| # RVC Samples (N) | 110 | 123 | 150 |
| # census takers | 2 | 3 | 4 |
| # Fish Species | 122 | 128 | 139 |
| # Individuals | 22,798 | 41,174 | 35,633 |
| Density (# indiv/sample) | 207 | 335 | 238 |
| Total Biomass (g) | 1,547,671 | 1,052,314 | 1,128,868 |
| Mean Biomass (g/sample) | 14,070 | 8,555 | 7,526 |
| # *Diadema* | 18 | 53 | 99 |
| Mean density (#/sample) | 0.16 | 0.43 | 0.66 |
| Frequency (proportion of samples occuring) | 0.09 | 0.20 | 0.22 |
| # Conch | 8 | 247 | 65 |
| Mean density (#/sample) | 0.07 | 2.01 | 0.43 |

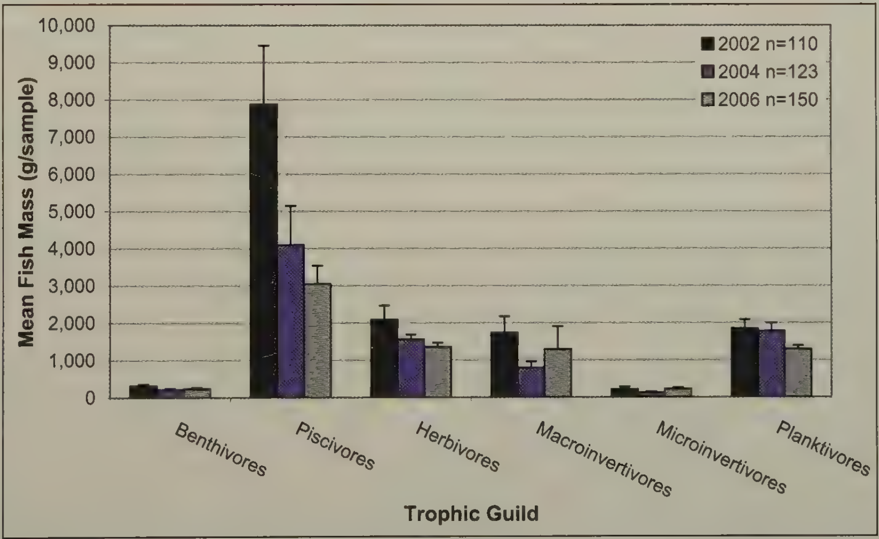


*Figure 4.13. Reeffish biomass per sample (mean + 1 SE) by trophic group over a four year interval. Species included in each trophic group provided in McClellan and Miller, 2003. Source: Miller et al., 2007; McClellan et al., unpub. data.*

## CURRENT CONSERVATION MANAGEMENT ACTIVITIES

Much valuable information has been gathered about the flora, fauna and threats to the ecology of Navassa. Since the NNWR was established in 1999, it has been faced with a documented increase in threats by foreign nationals, mainly Haitians, conducting commercial and subsistence fishing and hunting activities on the Refuge. Challenges to effective management are related to the island's remote location, an absence of local management presence, and an absence of solid quantitative fishery data. Currently, no practicable mechanism exists whereby the NNWR can efficiently or economically document, manage, or address these threats. Although active management has been limited, work begun by a Haitian non-governmental organization, the Foundation for the Protection of Marine Biodiversity, is beginning to educate local fishers.

Discussions are now underway for developing a strategy to deal with the unauthorized fishing incursions into NNWR via a collaborative conservation effort with federal agency members of the U.S. Coral Reef Task Force, academic institutions and non-governmental conservation organizations. The development of a Navassa NWR collaborative conservation effort will strengthen the National Wildlife Refuge System's natural resource management efforts. It is foreseeable that a similar approach can be employed for other remote, insular U.S. possessions, especially National Wildlife Refuges in the Pacific Ocean.

## OVERALL CONCLUSIONS AND RECOMMENDATIONS

It is clear that Navassa reefs, despite their remoteness from many types of local anthropogenic stress, are undergoing rapid change. Both expanded (but possibly stabilized) fishing pressure and disturbances, such as coral bleaching and disease events, are resulting in rapid loss of live coral cover, including loss of large coral colonies, and reductions in the size and abundance of reef fishes. The jurisdictional/management challenges for Navassa, meanwhile, do not abate. The occurrence of severe coral disease and bleaching events in this relatively deep (25-30 m) and remote location support the hypothesis that coral loss in the Caribbean is a regional phenomenon, and effective conservation and management measures to reverse this trend are not obvious.

# REFERENCES

Bohnsack, J.A. and S.P. Bannerot. 1986. A stationary visual census technique for quantitatively assessing community structure of coral reef fishes. NOAA NMFS Technical Report 41. Seattle, WA. 15 pp.

Carpenter, R.C. and P.J. Edmunds. 2006. Local and regional scale recovery of *Diadema* promotes recruitment of scleractinian corals. Ecol. Lett. 9: 271-280.

Littler, M.M., D.S. Littler, and B.L. Brooks. 1999. The first oceanographic expedition to Navassa Island, USA: Status of marine plant and animal communities. Reef Encounter 25: 26-30.

McClellan, D.B. and G.M. Miller. 2003. Reef fish abundance, biomass, species composition and habitat characterization of Navassa Island. pp. 24-42. In: Miller MW (ed.). Status of Reef Resources of Navassa Island. NOAA Technical Memorandum NMFS SEFSC 501. Miami, FL. 119 pp. http://www.aoml.noaa.gov/general/lib/tm_501.pdf

Miller, M.W. (ed.). 2003. Status of Reef Resources of Navassa Island. NOAA Technical Memorandum NMFS SEFSC 501. Miami, FL. 119 pp. http://www.aoml.noaa.gov/general/lib/tm_501.pdf

Miller, M.W. and C.L. Gerstner. 2002. Reefs of an uninhabited Caribbean island: fishes, benthic habitat, and opportunities to discern reef fishery impact. Biol. Conserv. 106: 37-44.

Miller, M.W., J. Schwagerl, D.B. McClellan, M.J.A. Vermeij, and D.E. Williams. 2005. The state of coral reef ecosystems of Navassa. pp. 135-149. In: J.E. Waddell (ed.). The state of Coral Reef Ecosystems of the United States and Pacific Freely Associated States: 2005. NOAA Technical Memorandum NOS NCCOS 11. Silver Spring, MD. 522 pp.

Miller, M.W., D.B. McClellan, J.W. Wiener, and B. Stoffle. 2007. Apparent rapid fisheries escalation at a remote Caribbean island. Environ. Conserv. 34: 92-94.

Miller, M.W. and D.E. Williams. 2007. Coral disease outbreak Navassa, a remote Caribbean island. Coral Reefs 26(1): 97-101.

Miller, M.W., R.B. Halley, and A. Gleason. In press. Reef Geology and Biology of Navassa Island. pp. 407-343. In: B. Riegl and R.E. Dodge (eds.). Coral Reefs of the USA. Coral Reefs of the World, Volume 1. Springer. 806 pp.

Piniak, G.A., C.M. Addison, B.P. Degan, A.V. Uhrin, and T.S. Viehman. 2006. Characterization of Navassa National Wildlife Refuge: A preliminary report for NF-06-05 (NOAA ship Nancy Foster, April 18-30 2006). NOAA Technical Memorandum NOS NCCOS 38. Silver Spring, MD. 48 pp.

Wiener, J.W. 2005. Oral history and contemporary assessment of Navassa Island fishermen. FoProBiM Report for NOAA National Marine Fisheries Service. 54 pp. http://www.sefsc.noaa.gov/PDFdocs/Navassa_Fishers_Report_Final_FoProBIM.pdf.

Williams, D.E. and M.W. Miller. 2005. Coral disease outbreak: pattern, prevalence, and transmission in *Acropora cervicornis*. Mar. Ecol. Prog. Ser. 301:119-128.

Williams, D.E., M.W. Miller, and K.L. Kramer. 2006. Demographic monitoring protocols for threatened Caribbean *Acropora* spp. corals. NOAA Technical Memorandum NMFS SEFSC 543. Miami, FL. 91 pp.

# The State of Coral Reef Ecosystems of Southeast Florida

Chantal Collier[1], Rob Ruzicka[1], Ken Banks[2], Luiz Barbieri[3], Jeff Beal[3], David Bingham[3], James Bohnsack[4], Sandra Brooke[5], Nancy Craig[2], Richard Dodge[6,7], Lou Fisher[2], Nick Gadbois[1], David Gilliam[6,7], Lisa Gregg[3], Todd Kellison[4], Vladimir Kosmynin[1], Brian Lapointe[8], Erin McDevitt[3], Janet Phipps[9], Nikki Poulos[1], John Proni[10], Patrick Quinn[2], Bernhard Riegl[6,7], Richard Spieler[6,7], Joanna Walczak[1], Brian Walker[6,7] and Denise Warrick[3]

Sidebars contributors:
Pulley Ridge & Middle Grounds: Walt Jaap[11], Sandra Brooke[3], Robert Halley[12]
Florida Reef Resilience Program: Chris Bergh[13] and Phil Kramer[13]

## INTRODUCTION AND SETTING

The northern extension of the Florida reef tract and a complex of limestone ridges run parallel to the subtropical Atlantic coastline of southeast Florida. Spanning 170 km from the northern border of Biscayne National Park (BNP) in Miami-Dade County to the St. Lucie Inlet in Martin County, the reefs and hardbottom areas in this region support a rich and diverse biological community (Figure 5.1). Nearshore reef habitats in southeast Florida include hardbottom areas, patch reefs and worm reefs (*Phragmatopoma* spp.) exhibiting abundant octocoral, macroalgae, stony coral and sponge assemblages. Offshore, coral reef associated biotic assemblages occur on linear Holocene *Acropora palmata* mid-shelf and shelf margin reefs that extend from Miami-Dade County to Palm Beach County (Lighty, 1977; Figure 5.2). Anastasia Formation limestone ridges and terraces colonized by reef biota characterize the reefs from Palm Beach County to Martin County (Cooke and Mossom, 1929).

*Figure 5.1. A coral reef assemblage in southeast Florida. Photo: D. Gilliam.*

The coastal region of southeast Florida is highly developed, containing one third of Florida's population of 16 million people (U.S. Census Bureau, 2006). Many southeast Florida reefs are located just 1.5 km from this urbanized shoreline. Despite their unique position as the highest latitude reefs along the western Atlantic seaboard, the reefs of southeast Florida have only recently received limited scientific and resource management attention. Andrews et al. (2005) discussed the reefs of southeast Florida and the critical need to implement actions that fill resource knowledge gaps and address conservation and threats to reef health. This report further examines and updates the list of stressors imperiling the health of southeast Florida's reefs, and presents information gained from new research, monitoring and management efforts to determine the extent and condition of reef resources in this distinctive region.

---

1 Florida Department of Environmental Protection
2 Broward County Environmental Protection Department
3 Florida Fish and Wildlife Conservation Commission
4 NOAA, Southeast Fisheries Science Center
5 Ocean Research and Conservation Association
6 Nova Southeastern University Oceanographic Center
7 National Coral Reef Institute
8 Harbor Branch Oceanographic Institute
9 Palm Beach County Environmental Resource Management
10 NOAA, Atlantic Oceanographic and Meteorological Laboratory
11 Lithophyte Research, LLC
12 U.S. Geological Survey
13 The Nature Conservancy

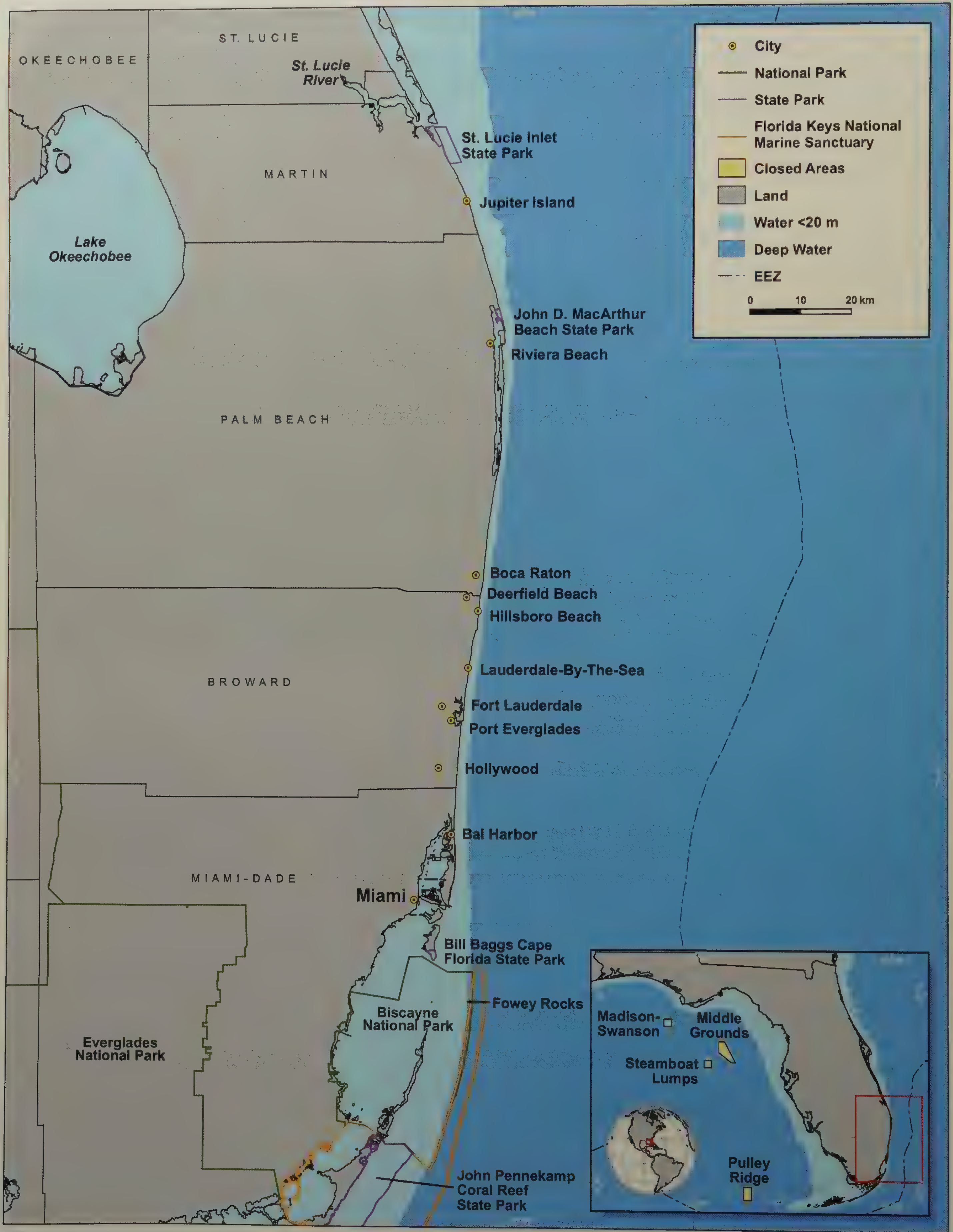

City
National Park
State Park
Florida Keys National Marine Sanctuary
Closed Areas
Land
Water <20 m
Deep Water
EEZ
0
10
20 km
OKEECHOBEE
ST. LUCIE
St. Lucie River
St. Lucie Inlet State Park
MARTIN
Jupiter Island
Lake Okeechobee
John D. MacArthur Beach State Park
Riviera Beach
PALM BEACH
Boca Raton
Deerfield Beach
Hillsboro Beach
Lauderdale-By-The-Sea
BROWARD
Fort Lauderdale
Port Everglades
Hollywood
Bal Harbor
MIAMI-DADE
Miami
Bill Baggs Cape Florida State Park
Fowey Rocks
Biscayne National Park
Everglades National Park
John Pennekamp Coral Reef State Park
Madison-Swanson
Middle Grounds
Steamboat Lumps
Pulley Ridge

Figure 5.2. A map of southeast Florida showing locations mentioned in this chapter. Inset map shows the location of Pulley Ridge and the Florida Middle Grounds in the Gulf of Mexico. Map: K. Buja.

### Pulley Ridge and Middle Grounds

The West Florida Shelf (northeastern Gulf of Mexico) carbonate platform is comprised of extensive hardbottom, ranging from low or moderate-relief rock outcrops and pavement to high-relief pinnacles and ridges. These hard substrates are colonized by sessile macrofauna such as Scleractinian corals, octocorals, black corals and sponges, which provide habitat for biologically diverse communities of invertebrates and fish, including large numbers of economically important reef fish such as snapper and grouper (Figure 5.3). The Gulf of Mexico Fisheries Management Council (GMFMC) recognized their importance by placing some of these features under protective legislation either as Marine Protected Areas (MPA), such as Madison Swanson and Steamboat Lumps, or as Habitat Areas of Particular Concern (HAPC) such as the Florida Middle Grounds (FMG) and Pulley Ridge (Gulf of Mexico and South Atlantic Fishery Management Council, 1982). The latter habitats are both dominated by shallow water coral reef communities, despite their atypical locations, and are described in more detail below.

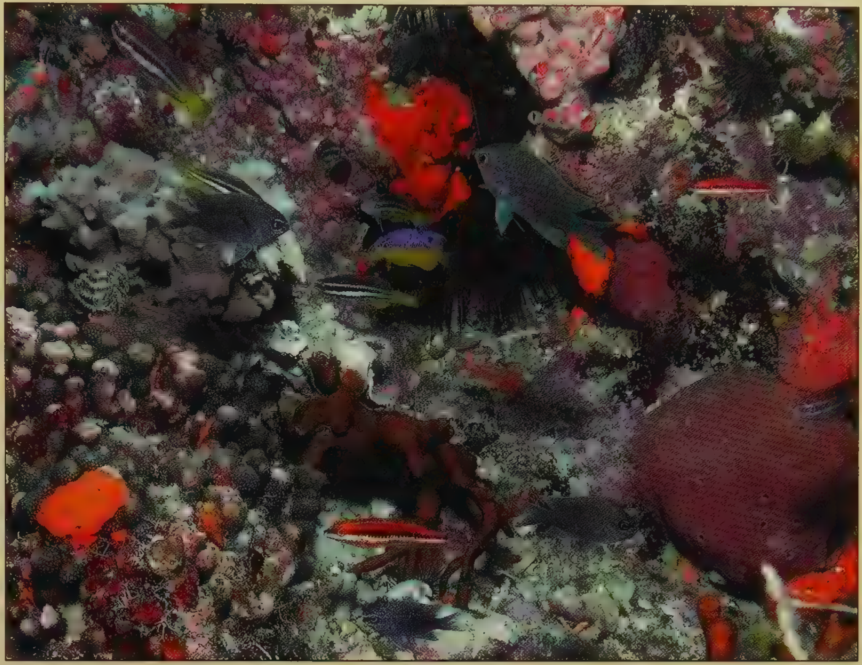


*Figure 5.3. The Florida Middle Grounds benthic community supports numerous species of algae, sponge, hydrocoral, scleractinian coral, invertebrates, long-spined urchin and fish. Photo: G.P. Schmahl.*

The FMG are located 137 km off the west coast of Florida and are comprised of a series of carbonate ledges trending north to northwest at shelf depths of 40-45 m, rising up to 15 m relief from the seafloor. At a latitude of 28.50° N, these ledges represent the northern-most coral reefs in the continental United States, and in 1982 the GMFMC designated 348 square nautical miles of the primary high relief and live bottom area a HAPC. Regulations prohibit coral removal (except by special permit) and the use of bottom tending fishing gear (bottom longlines, traps, pots and bottom trawls). These areas were originally surveyed in the mid 1970's (Hopkins et al., 1977), and a resurvey of the same areas in 2003 revealed little or no changes in the sessile benthic community (algae, sponges, octocorals, Scleractinian and Hydrozoan corals); however, grouper and snapper populations have declined significantly (Coleman et al., 2003). Multibeam mapping of portions of the FMG HAPC was completed in 2006.

Pulley Ridge is a rocky feature 1-15 km wide and 1-10 m high in 60-90 m water depth between the FMG and the southern margin of the Florida shelf (Jarrett et al., 2005). This structure provides substrate for reef communities, and the southernmost 30 km of this feature supports the deepest hermatypic coral reef in the United States (Culter et al., 2006). The Pulley Ridge coral reef ecosystem has up to 60% coral cover over broad areas. The dominant zooxanthellate Scleractinia are *Leptoseris cucullata*, *Agaricia lamarcki* and *Agaricia fragilis*. Less common species include *Madracis formosa*, *M. pharensis*, *M. decactis*, *Montastraea cavernosa*, *Porites divaricata*, *Scolymia cubensis* and *Oculina tenella* (Halley et al., 2005). The area was designated an HAPC by the GMFMC in 2005. Gear restrictions and coral protection were enacted to protect the nearly 250 km$^2$ coral-rich zone. Sporadic remotely-operated vehicle (ROV) surveys since 1999 indicate that coral is generally healthy and there has been no evidence of bleaching or disease. A multi-institutional expedition to Pulley Reef took place in June 2005, and for the first time limited sampling was undertaken by technical divers in 65 m water depth. Samples will verify identifications that to-date have been made primarily from photographs and limited dredged material.

## ENVIRONMENTAL AND ANTHROPOGENIC STRESSORS

### Climate Change and Coral Bleaching

Climate change related events such as sea level rise and temperature increases may affect coral reefs. Locally or regionally, storm pattern changes may directly impact coral communities, and changes in rainfall may affect sedimentation, salinity, and nutrient and pollutant inputs (Edwards,1995). Data from 1890-2000 indicate a decline in rainfall since the 1960s, and global climate models predict a reduction in precipitation for south Florida that will ultimately decrease the volume of surface runoff (South Florida Water Management District, 1996). This may, in itself, be beneficial to reef biota. For example, Dodge and Helmle (2003) found that salinities lower than normal seawater slowed coral growth rates. However, landscape (urbanization) can influence rainfall (Pielke et al., 1999), so predicting future rainfall levels is complicated by other factors, including water use patterns by an increasing local population.

As a low elevation coastal region, sea level rise is of great concern for southeast Florida. Measured (multi-satellite altimetry) global sea level rise averaged 2.4 mm/yr between 1992-2003 (Trimble et al., 2006). Wanless (1989) reported that since 1932, sea level rise in south Florida has accelerated and more recent rates are 2-4 mm per year. Others estimate probable rates of 15±3 mm/yr over the next century (Buddemeier and Smith,1998). These high rates could directly impact corals by shifting them to a deeper, lower light position in the water column. Southeast Florida's reefs are relict *Acropora palmata* reefs colonized by reef biota and in the short term may not be as sensitive as extant acroporid reefs. However, secondary impacts, such as increased sedimentation and turbidity from flooding and erosion, could degrade water quality and affect reef growth.

Many tropical reefs live near their upper lethal temperature limits (Edwards, 1995). High latitude southeast Florida reefs have likely adapted to lower temperatures, but their ability to adapt to higher temperatures is unknown. El Niño events can cause increases in water temperature on an annual scale, and increases on a longer scale are widely predicted by scientists. In general, exposure for only a few days to temperatures of 3-4°C above normal summer ambient maxima or for several weeks to elevations of only 1-2°C above maxima can cause coral bleaching. Recovery depends on exposure time and magnitude of elevation. Coral bleaching reduces growth and impairs reproduction, and even sub-bleaching temperature rise can affect growth, reproduction and recruitment (Edwards, 1995).

Mass bleaching events similar to those reported in the Caribbean have not been reported off southeast Florida. Yearly monitoring of the reef communities off Broward County since 2000 shows that the mean percentage of bleached (fully bleached, partially bleached and pale) colonies has been <4.5%, with a long-term mean <3% (Gilliam, et al., 2006). A bleaching event affecting *Montastraea cavernosa* and *Diploria clivosa* colonies was noted near the St. Lucie inlet (Martin County) in winter/spring 2006 and may have been due to 14 months of continuous fresh water release from Lake Okeechobee (Jeff Beal, pers. obs.).

### Disease

Two ongoing southeast Florida reef monitoring efforts, the Broward County Marine Biological Monitoring Program and the Southeast Florida Coral Reef Evaluation and Monitoring Project (SECREMP), record coral disease presence. Details on both monitoring programs and the results of their work can be found later in this chapter. Although SECREMP has identified coral diseases in three Florida counties (Miami-Dade, Broward and Palm Beach), occurrences are low, with generally less than one diseased colony identified per site (Gilliam, 2006). Since 2000, the Broward County program has documented diseased colony abundance and documented that disease prevalence is <0.5% of the community (Gilliam et al., 2006). The more common stony coral species affected by disease have included *Montastraea cavernosa*, *Siderastrea siderea*, *Solenastrea bournoni* and *Dichocoenia stokesi*. Identified diseases include black band disease, white plague and dark-spots. White band disease has been identified in the *Acropora cervicornis* thickets offshore Broward County (Gilliam, 2006); however, mortality from disease appears to be low (Vargas-Angel et al., 2003). Neither monitoring program collects quantitative data on gorgonian diseases; however, some diseased common sea fan colonies (*Gorgonia ventalina*) and sea plume colonies (*Pseudopterogorgia* spp.) have been noted with mortality caused by the fungus *Aspergillus sydowii*.

### Tropical Storms

Significant new observations of the effects of tropical storms on reef environments in Florida have been made in the last decade. The placement of measurement systems within the coastal ocean in order to record environmental parameters prior to, during and after the passage of a storm has yielded new insights into storm effects. Passing storms may vary considerably in intensity, size and rain content. The distance of the storm from a reef is also important; although the eye of a storm may be distant, the region of maximum wind and storm surge could be much closer to the reef of interest.

There are several potential effects associated with passing hurricanes that have the prospective ability to affect reefs. These effects include at least the following: 1) enhanced sediment resuspension; 2) alteration of the surface wave spectrum impinging on the reefs; 3) alteration in both direction and magnitude of the ambient current field; 4) reduction in ambient light; 5) upwelling of cold, nutrient-rich, deeper ocean water; 6) an increase in runoff and water flow through inlets and cuts; and 7) direct mechanical stress on corals and associated benthic organisms.

The Florida Area Coastal Environment (FACE) program had an array of instrumentation placed in coastal waters during the busy hurricane season of 2005 and during the slow hurricane season of 2006. In the 2005 season, the reefs off southeast Florida were affected by hurricanes Katrina, Wilma and Rita. Each of these hurricanes generated significant sediment resuspension and introduced cold, upwelled water to the vicinity of the reefs. Water temperature drops of 5-10°C and more were associated with the storms (Proni, pers., comm.; FACE, unpub. data). Hurricane Wilma traveled from the west to the east over Florida while Katrina and Rita both traveled from the east to the west over Florida (Figure 5.4).

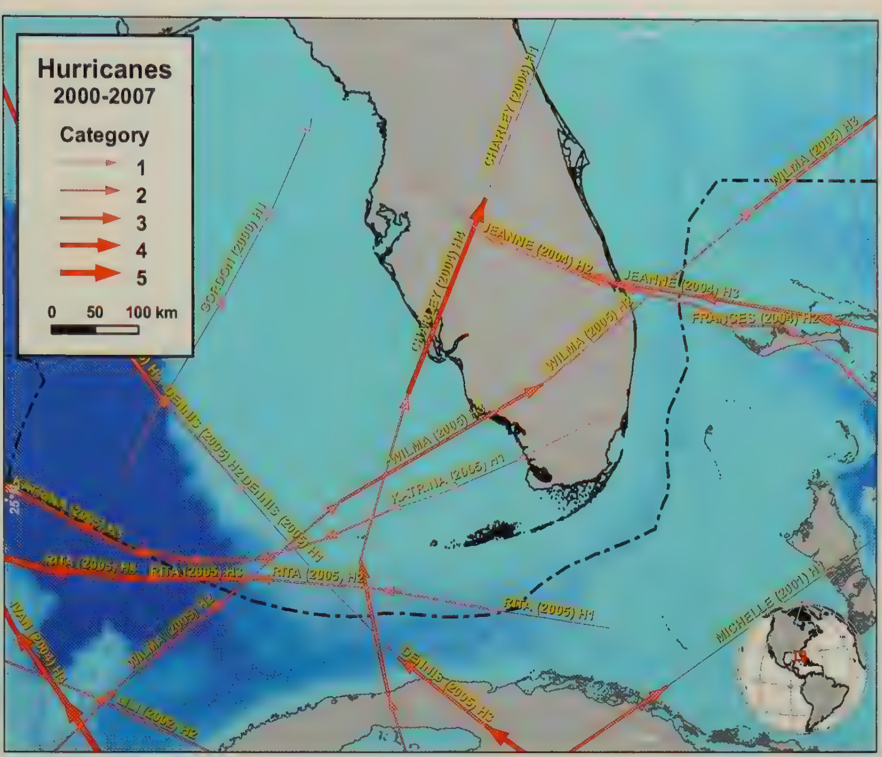


*Figure 5.4. The paths and intensities of tropical storms and hurricanes affecting southeast Florida from 2000-2007. Map: K. Buja. Source: http://maps.csc.noaa.gov/hurricanes/.*

Figure 5.5 shows an example of data from *in situ* instrumentation including 10 minute average wind speed in meters per second and acoustic backscatter for two frequencies measured between October 21-28, 2005 with a bottom mounted Acoustic Doppler Current Profiler in 17 m of water off Miami. Backscatter measurements can be taken to represent approximate indications of the level of sediment resuspension. The level of backscatter preceding the peak winds of Hurricane Wilma is contrasted with the level after the hurricane passed. Even four days after passage of Hurricane Wilma the backscatter levels had not returned to pre-hurricane passage levels. The extended period of elevated backscatter levels (particularly the 1200 kHz values) is coincident with the presence of long period (16 second) surface waves that radiated from Wilma after it had left the region.

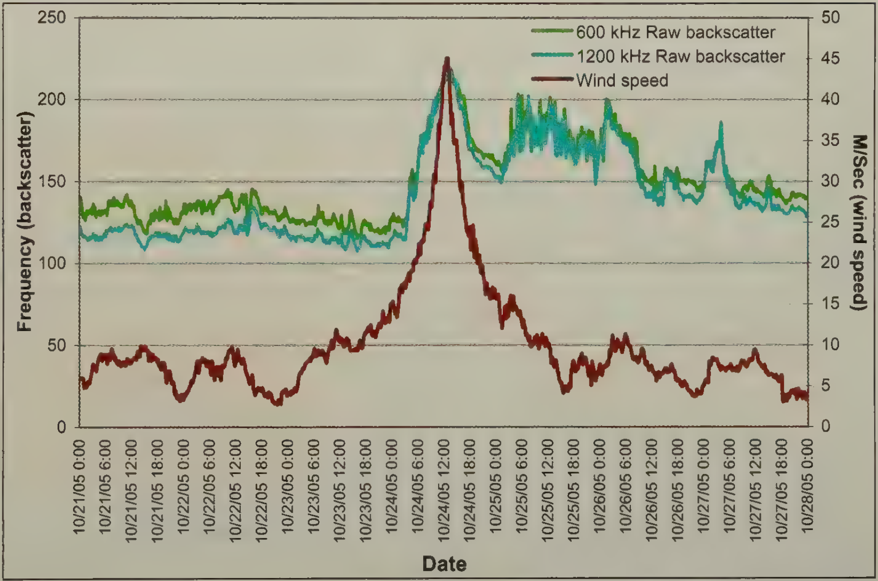


*Figure 5.5. Ten minute average wind speeds compared with sediment resuspension acoustical backscatter during Hurricane Wilma of 2005.* ***Note****: The data presented in this figure are for research purposes only. They are experimental products created at NOAA-AOML and must undergo additional quality control and other checks before release as official products. Source: NOAA Atlantic Oceanographic and Meteorological Laboratory, unpub. data.*

## Coastal Development and Runoff

Coral reefs and related hardbottom communities of southeast Florida are located offshore and in close proximity to one of the most developed and populated areas of the United States. According to Florida Statistical Sources, the population in southeast Florida grew by 139,000 from 2003-2005 (University of Florida, 2006) demonstrating an accelerated trend. Although some development has shifted from the shoreline to 10-25 km inland, it still continues in close proximity of the coastline. Within this area, the population increased by 31-64% from 1990-2002 (U.S. Census Bureau, 2007b). These coastal areas have had continued development in diverse forms such as dredging for navigation, construction of marinas, beach nourishment, geotechnical drilling, and installation of pipelines and cables. Impacts associated with these activities can lower water quality conditions and increase the number of injuries to reef and hardbottom organisms. In addition, as the population increases, damage to coral reefs and hardbottom communities may be attributed to elevated levels of diving, snorkeling and fishing.

According to the Integrated Water Quality Assessment for Florida 2006, poor water quality was found in 50% of the river and stream miles, 60% of the lake acres (excluding Lake Okeechobee) and 60% of the square miles of estuaries (Florida Department of Environmental Protection, 2006). The same assessment states that in spite of Florida's successes in protecting its water resources, there is an alarming trend of increasing levels of phosphorus and nitrogen in surface and ground water. The growth of urban development within southeast Florida has resulted in substantial increases of surface water runoff due to increased impervious areas from construction of homes, roads, parking lots and other structures, which prevent water percolation. As a result, storm water runoff concentrates pollutants generated by an increasing population and channels it to the ocean. It has been suggested that the increased frequency of algal and cyanobacterial blooms on southeast Florida reefs is directly related to the enrichment of phosphorous, nitrogen and other nutrients attributed to terrestrial runoff. Increases in development also add to sewage impacts in nearshore waters as discussed below.

### Coastal Pollution

Since the publication of The State of Coral Reef Ecosystems of Florida (Andrews et al., 2005), a number of stressors related to coastal pollution have risen to the forefront. One of the most newsworthy has been the issue of ocean wastewater outfalls and the impacts of wastewater effluent to reefs. There are four methods of effluent disposal in Florida, ocean outfalls, surface discharges, deep well injection and reuse (Trnka et al., 2006). There are six wastewater effluent outfalls in the southeast Florida region, which require secondary treatment of effluent, removing at least 85% of biodegradable organics and suspended solids. Combined, the six outfalls discharge up to 300 million gallons/day of minimally treated wastewater into the Atlantic Ocean (FDEP, unpub. data). The average monthly nutrient loading to coastal waters from these outfalls from 2000-2005 ranged from 1,327 pounds/day to 24,142 pounds/day for total nitrogen and 49 pounds/day to 3,443 pounds/day for total phosphorus (Craig, pers. comm.; FDEP, unpub. data). The large range in loading estimates can be attributed, for the most part, to differences in the average volume of water discharged, on a monthly basis, from the individual plants (Trnka et al., 2006). The fate of these nutrients in the coastal oceanographic setting is unknown but is currently under study by NOAA, as well as investigations aimed at distinguishing natural changes on the reefs from those that can be attributed to anthropogenic causes (NOAA Keynotes, 2006). Tichenor (2004b) reported a correlation between the existence of cyanobacterial blooms in Palm Beach County and an upstream wastewater outfall. Fauth et al. (2006) completed a feasibility study using enzymatic biomarkers to identify stress in *Porites astreoides* around inlets and wastewater outfalls and found that stress responses in the coral around the Hollywood wastewater outfall were consistent with sewage exposure. This project is slated to continue through 2009.

### Tourism and Recreation

Tourism and recreation are two of Florida's highest grossing industries, generating a combined $62 billion in sales in 2005. Reef-based tourism and recreation are significant economic assets for the southeast Florida region inclusive of Miami-Dade, Broward, Palm Beach and Martin Counties. Results from two non-concurrent studies of natural and artificial reefs in southeast Florida (Table 5.1) indicate that a total of $2.3 billion in sales and $1.1 billion in income were generated annually from natural reef related expenditures, while supporting more than 36,000 jobs in the region (Johns et al., 2001; Johns et al., 2004). It is estimated that 15.2 million person days are spent on natural reefs in the southeast Florida region annually with primary activities including snorkeling, scuba diving and fishing (Table 5.1). Although a little less than half (7.4 million) of the estimated person days spent on reefs were by visitors, tourists contributed to $1.28 billion in sales, accounting for 72% ($791 million) of the reef-related income generated for the region. The additional high use of coral reefs by residents of southeast Florida is explained by the fact that they lie adjacent to three of the four most populous counties in Florida (U.S. Census Bureau, 2007a), and >20% of all 2005-2006 state recreational saltwater fishing licenses were purchased by residents within these counties.

*Table 5.1. Estimate by county of socioeconomic value of recreation and tourism related activities occurring on natural coral reef ecosystems of southeastern Florida. Data for Broward, Miami-Dade, and Palm Beach counties from Johns et al., 2001. Data for Martin County from Johns et al., 2004.*

| ATTRIBUTE | BROWARD | MIAMI DADE | PALM BEACH | MARTIN | TOTAL |
|---|---|---|---|---|---|
| Total Person Days (millions) | 5.40 | 6.30 | 2.80 | 0.70 | **15.2** |
| Snorkeling and Diving Person Days (millions) | 2.84 | 2.24 | 1.68 | 0.08 | **6.84** |
| Fishing Person Days (millions) | 2.58 | 3.96 | 1.14 | 0.45 | **8.13** |
| Sales (millions of $) | 1,108 | 878 | 354 | 6 | **2,346** |
| Income (millions of $) | 547 | 419 | 141 | 3 | **1,110** |
| Jobs | 18,600 | 12,600 | 4,500 | 84 | **35,784** |

### Fishing

Total fishing activity in the southeast Florida region reflects Florida's increasing population. The southeast Florida region accounted for more than 20% of all resident recreational saltwater fishing licenses sold in Florida in 2005-2006. Precise data on fishing effort on coral reefs do not exist, but are reflected by state-wide and regional fishing statistics (Ault et al., 2005). Since 1964, the number of registered recreational boats in the southeast Florida region has grown approximately 350% (Figure 5.6). Although the number of registered vessels actually used for fishing is unknown, the number of recreational saltwater fishing licenses purchased annually in Florida by both residents and non-residents has risen by 25% since 1992 (Figure 5.6; McDevitt, pers. obs.). Florida recreational fishery estimates from 2001-2005 indicate that more than 6.4 million anglers average 27.2 million marine fishing trips annually (NMFS, 2005). In the southeast Florida region alone, two recent (2000-2001, 2003) non-concurrent studies estimate that 6.029 million person days were spent fishing on the natural reefs annually (Johns et al., 2001; Johns et al., 2004). The number of commercial vessel registrations in the southeast Florida region has grown at a lower rate (about a 100% increase) since 1964, but the number of state-issued individual and vessel commercial licenses has been decreasing over the last decade (Figure 5.6; Fish and Wildlife Research Institute, unpub. data). Fishing power (the proportion of stock removed per unit of fishing effort) has probably increased substantially in recent decades because of technological advances in fishing tackle, hydroacoustics (depth sounders and fish finders), navigation (charts and global positioning systems), communications and vessel propulsion (Bohnsack and Ault, 1996; Mace, 1997).

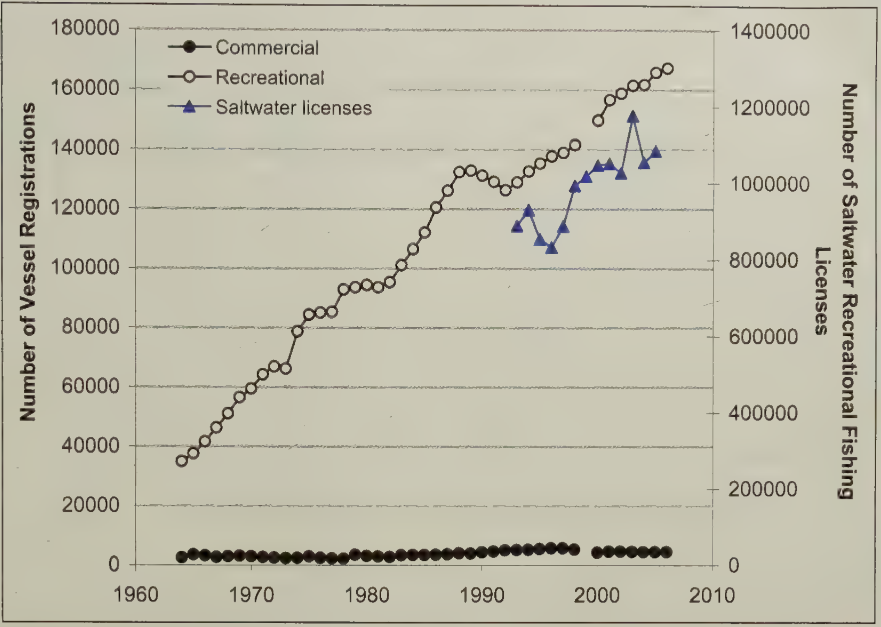


*Figure 5.6. The number of commercial and recreational vessel registrations by year for the southeast Florida region. No data were available for 1999. Number of saltwater recreational fishing licenses purchased in Florida, both residential and non-residential, for the period of 1993-2006. Source: Florida Fish and Wildlife Conservation Commission, unpub. data.*

Fishing can impact coral reefs by removing targeted species and by killing non-target species as bycatch, both of which may decrease abundances of important keystone species and cause cascading ecological effects. Several fishing techniques (e.g., trawling and trapping) cause habitat damage and because fishing is often size-selective, concerns exist about the long-term viability of heavily exploited stocks (e.g., groupers and snappers) especially when fishers target spawning aggregations. Fishing stress can be compounded when combined with other stressors such as pollution and habitat damage (Wilkinson, 1996).

## Trade in Coral and Live Reef Species

Florida Administrative Code rule 68B-42 and the Federal Fishery Management plan prohibit the removal and possession of wild live rock, coral (hard, stony, fire and black corals), and common and Venus sea fans in state waters and the adjacent Exclusive Economic Zone with few exceptions allowed for research collections. The recreational and commercial collection of wild octocorals (except the two prohibited species of sea fans) and numerous tropical-ornamental reef species is regulated by state and federal fishery management agencies. Several species of coral and seahorses indigenous to Florida are listed as Convention on International Trade in Endangered Species (CITES) species, and their international trade is regulated by the U.S. Fish and Wildlife Service. Few reef species that are indigenous to Florida are used in food, curio or pharmaceutical industries, which significantly decreases their demand in international markets. Florida reef species are primarily utilized in the tropical-ornamental aquarium industry within the United States. Although regulated, the extraction of reef species may still threaten the health of coral reefs because there is a general lack of research and scientific knowledge to support the current management plans, limited enforcement and ecological implications that may extend from over-fishing.

## Ships, Boats and Groundings

Impacts from large vessel groundings and anchor or cable drag events can result in immediate and extensive long-term injuries to coral reefs and associated organisms. Vessel hulls, anchors and propellers can fracture and crush coral reef framework (Figure 5.7), scrape the reef substrate, and dislodge corals and sponges, often leading to total loss of all biota (U.S. Coral Reef Task Force, 2000).

The southeast Florida region has experienced a high number of vessel groundings and anchor and cable drag cases over the last 30 years. Most notably, Broward County experienced 11 known ship groundings and six known anchor drag cases from 1994–2006, which resulted in over 11 acres of damaged reef habitat (Figure 5.8; Collier et al., 2007). The majority of these cases have been associated with the Port Everglades anchorage which services cruise ships, cargo vessels and petroleum carriers. Many large commercial carriers use the offshore Port Everglades anchorage while waiting for berths inside the Port. The Port Everglades' anchorage consists of two anchorage areas which are located north of the Port Everglades entrance channel, situated between the second and third reef tracts, and east of the third reef tract, respectively (Figure 5.8). The proximity of the anchorage areas to reefs, coupled with navigational error, has resulted in the high number of groundings in this area. In October 2007, the U.S. Coast Guard issued a Notice of Proposed Rulemaking to eliminate Port Everglades anchorage area A, expand anchorage area B into deeper waters and away from the reefs, and limit the time a vessel may remain in the anchorage. The proposed action was a direct result of recommendations by the Port Everglades Harbor Safety Committee, which includes representatives from federal, state and county agencies, and local maritime and environmental stakeholders.

In addition to damage created by large vessel groundings and improper anchoring, chronic damage caused by anchors from smaller recreational vessels also result in widespread cumulative damage. In 2006, there were over 165,000 recreational boats registered in the southeast Florida region, many of which anchor on the reef to fish, dive, and snorkel (Johnson et al., 2007). Several large-scale marine spectator events held in southeast Florida each year draw thousands of recreational vessels that congregate in relatively small areas and anchor on reefs to observe the events (Bingham, pers. comm.). In March 2007, a 73 ft. motorized catamaran attempted to anchor, partially sank, then ran aground in 6 m of water off northern Miami-Dade County, causing extensive damage to corals and hardbottom habitat. Through the Southeast Florida Coral Reef Initiative (SEFCRI), a document was produced to provide guidance and recommendations for rapid response to, and restoration of, coral reef injuries in southeast Florida (Collier et al., 2007).

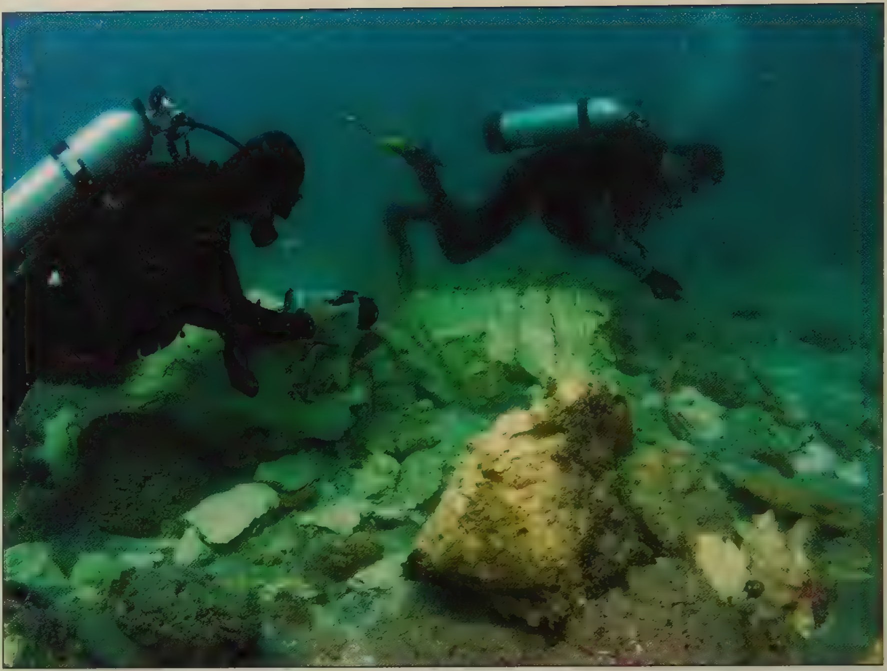


*Figure 5.7. Divers assess coral injuries from a vessel grounding. Photo: D. Gilliam.*

## Marine Debris

With increasing anthropogenic pressure on reefs, specifically fishing and diving, reef debris has become an increasing problem. In 2006, during one volunteer waterway cleanup, 446 bait containers, 274 buoys, 920 fishing lines, 404 fishing lures/light sticks and 1,854 pieces of rope were recovered, which represents a third of the categories attributed to boating operations (Ocean Conservancy, 2006). Another cleanup operation estimated fishing line, lures and light sticks as 77.9% of the debris removed during an underwater cleanup (Ocean Conservancy, 2005). Hook-and-line fishing gear accounted for 87% of all debris reported in the Florida Keys responsible for tissue abrasion and causing partial or entire mortality of many benthic organisms, such as branching gorgonians (Chiappone et al., 2005). Since 2005, several debris cleanup events have been conducted within St. Lucie Inlet Preserve State Park in Martin County through partnerships with state agencies, commercial fishermen and a local non-profit organization. During a one-day event, over 300 gallons of debris (mostly netting) were collected (Herren et al., 2007). Derelict nets used to catch bait and Spanish mackerel remain a source of debris in the park and impact corals and other benthic invertebrates.

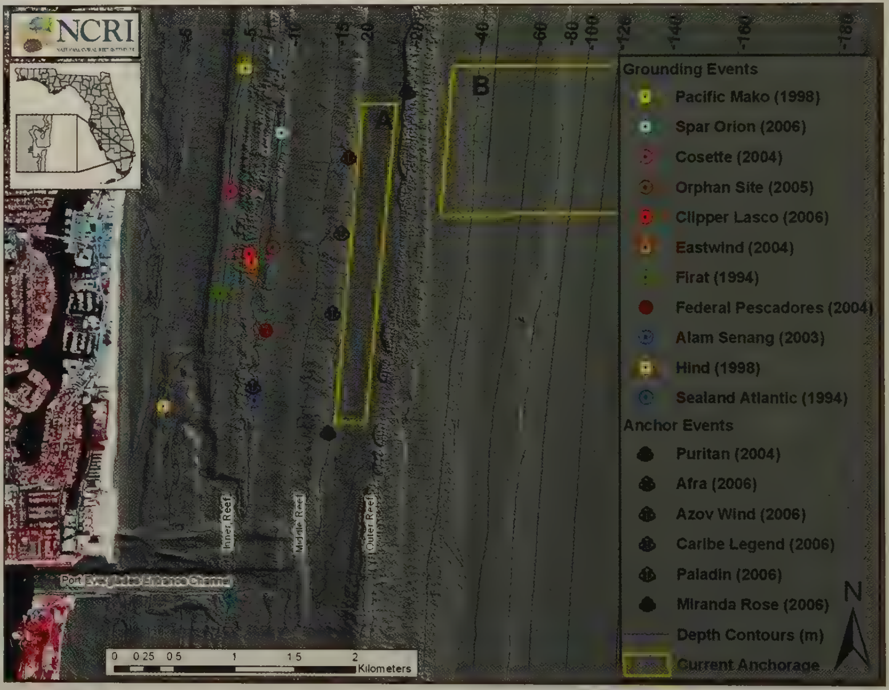

NCRI
A
B
Grounding Events
Pacific Mako (1998)
Spar Orion (2006)
Cosette (2004)
Orphan Site (2005)
Clipper Lasco (2006)
Eastwind (2004)
Firat (1994)
Federal Pescadores (2004)
Alam Senang (2003)
Hind (1998)
Sealand Atlantic (1994)
Anchor Events
Puritan (2004)
Afra (2006)
Azov Wind (2006)
Caribe Legend (2006)
Paladin (2006)
Miranda Rose (2006)
Depth Contours (m)
Current Anchorage
Inner Reef
Middle Reef
Outer Reef
Port Everglades Entrance Channel
0 0.25 0.5 1 1.5 2 Kilometers
N

*Figure 5.8. U.S. Coast Guard designated anchorages at Port Everglades outlined in yellow, with locations of recent vessel groundings and known anchoring events. Image: B. Walker.*

## Aquatic Invasive Species

Florida's marine environment has become a haven for many non-indigenous species, particularly those imported for aquaculture, the aquarium trade or introduced by ships from other tropical and sub-tropical regions. Some of these species are ephemeral and do not survive because they are consumed by predators or cannot acclimate to a new habitat. The species that thrive, however, negatively impact reef ecosystems by competing with and displacing native species. Established invasive species in southeast Florida include macroalgae, mollusks, crustaceans, cnidarians and fish.

Macroalgal invasions pose the greatest risk to southeast Florida's coral reefs. Since 1990, a succession of native and non-native macroalgae in the genera *Caulerpa* and *Codium* formed widespread blooms on reefs in Palm Beach and Broward Counties, resulting in mortality of reef biota (Lapointe, 1997; Lapointe et al., 2005a). In 2001, the Pacific species *Caulerpa brachypus f parvifolia* was discovered on reef communities off Riviera Beach (Lapointe et al., 2005b). This invasion expanded northward to Ft. Pierce, forming thick mats that covered up to 90% of reefs in northern Palm Beach County and resulted in loss of biodiversity and fisheries habitat. In August 2004, hurricanes Frances and Jeanne temporarily removed the *C. brachypus* blooms, but the species reestablished itself in winter 2007 (Lapointe et al., 2006). The extent of cyanobacterial blooms on the reefs of Broward County, reported by Paul et al. (2005), has lessened, although they persist at the site studied by Tichenor (2004b) in Palm Beach County. Periodic, short-lived blooms continue to occur offshore of Broward County, however. Land-based nutrient pollution may facilitate the expansion of native and non-native species to levels that cause environmental degradation.

A majority of non-indigenous fish in Florida have been freshwater or freshwater/marine introductions (157), but 21 marine species have been recorded as well. The number of introduced species in Florida has steadily risen each decade (South Florida Information Access, http://sofia.usgs.gov). Two Indo-Pacific lionfishes have established themselves on the east coast of the U.S. (Whitfield et al., 2002; Semmens et al., 2004). Both the Red Lionfish (*Pterois volitans*) and its congener, the Devil Firefish (*P. miles*), have been imported extensively for the aquarium trade and were first observed on local reefs in 2002 (Whitfield et al., 2002). Lionfish were most likely introduced as a result of an aquarium trade release (Semmens et al., 2004) and although they are not abundant on southeastern Florida reefs, they have established large populations on northern U.S. temperate reefs (Whitfield et al., 2007). A list of other exotic reef fishes inhabiting southeast Florida's reefs can be found on the Reef Environmental Education Foundation (REEF) Web site (http://www.reef.org/programs/exotic).

There are at least 60 non-native species of invertebrates that have been reported in the marine and freshwater habitats of Florida. These species belong to the phylla Mollusca (26 species), Crustacea (21 species), Cnidaria (six species), Annelida (three species), Entoprocta (Bryozoa; two species) and Chordata (tunicates; two species). Invertebrate non-indigenous species are often introduced by ship ballast rather than the aquarium trade. The green mussel, *Perna viridis*, is native to the Indo-Pacific but has invaded estuaries on both coasts of Florida, specifically in Tampa Bay and St. Augustine (Baker et al., 2003). Although not necessarily invasive to southeast Florida at present, the Australian spotted jellyfish, *Phyllorhiza punctata*, is cause for concern because a bloom of these jellyfish had a significant economic impact on the shrimp fishery in the Gulf of Mexico in 2000 (Perry et al., 2000). While this outbreak was relatively confined, there is the possibility that future blooms may occur over broad areas and potentially affect fish spawning success because the jellyfish preys on the eggs and larvae of many species (Graham et al., 2003).

For additional information on the status and trends of invasive and non-indigenous species in Florida please visit http://www.ccfhr.noaa.gov, http://nas.er.usgs.gov and http://sofia.usgs.gov. The U.S. Geological Survey's Nonindigenous Aquatic Species Alert System allows the public to report alien species sightings and functions as an early alert system for managers.

## Security Training Activities

Military security training activities are not recognized as a threat to coral reefs in southeast Florida.

## Offshore Oil and Gas Exploration

There continues to be no oil or gas drilling operations in the state waters of southeast Florida.

## Other

### *Subsea Engineering Projects: Gas Pipelines and Fiber Optic Cables*

Installation of fiber optic cables and construction of gas pipelines can have a major impact on coral reefs. Stony corals, gorgonians and sponges can become abraded or dislodged during pipeline installation, increased sedimentation and leaks of drilling mud and lubricants during horizontal directional drilling (HDD) can smother corals, and resultant increases in turbidity reduces the amount of light necessary for healthy function. Although cables have a small impact footprint, corals and other reef organisms can be chronically impacted by shading and abrasion (PBS&J, 1999). Storm events can lead to movement of cables on the substrate, which can result in abrasion of corals and reef substrate. Over the last twenty years there has been over 12 acres of nearshore reef damaged during pipeline installation in southeastern Florida (U.S. Fish and Wildlife Service. SE Region, 2004). There are two gas pipeline projects currently being reviewed for permits in the southeast Florida region, AES Ocean Express and Calypso U.S. Pipeline, LLC, and they are expected to incur greater than seven acres and 4.5 acres of reef damage, respectively. Both of these projects plan to pipe liquid natural gas from facilities in the Bahamas to exit points in Broward County. However, as an alternative, Calypso is proposing a deepwater port approximately 10 miles offshore from Port Everglades.

There have been no new fiber optic cable permits issued since 2001 for the southeast Florida region (Vince, pers. comm.). Since 2003, recommendations have been made to minimize impacts to reef systems, such as decreasing turbidity thresholds, using reef gaps to lay cables, implementation of tunneling and elimination of HDD, coral relocation for corals at risk, and increased monitoring and mitigation. Through the Southeast Florida Coral Reef Initiative, a best management practices document for construction, dredge and fill and other activities near coral reefs is in development (Collier, pers. obs.).

## CORAL REEF ECOSYSTEMS—DATA-GATHERING ACTIVITIES AND RESOURCE CONDITION

Current coral reef monitoring and assessment activities in southeast Florida, including activities that are discussed below, are listed in Table 5.2. Figure 5.9 presents both water quality and biological monitoring sites in Southeast Florida.

*Table 5.2. Coral reef monitoring programs in the Southeast Florida region. See next page for funding/partner acronym definitions. Source: FDEP.*

| PROGRAM | OBJECTIVES | START | FUNDING | PARTNERS |
|---|---|---|---|---|
| Miami-Dade County Water Quality Monitoring Network (MDCWQMN; DERM) | Monitor status and trends in water quality parameters to evaluate progress toward achieving/maintaining water quality standards and protecting/restoring living marine resources in South Florida coastal waters. Limited to Biscayne Bay and associated canals and tributaries. | 1979 | SFWMD, DERM | 24 municipalities of Miami-Dade County, SFWMD, FDEP |
| Palm Beach County Environmental Resource Management Reef Monitoring Program (PBCERM) | Long-term non-destructive *in situ* monitoring of fish composition, abundance and size structure on artificial reefs. Benthos monitoring added (1998) and fish and benthos on natural reefs added (2004). Offshore reef monitoring expanded (2006). Nearshore aerials flown/digitized county-wide annually. Pilot coastal water quality monitoring program targeting wastewater outfalls and Lake Worth Inlet begins 2008. | 1983 | PBCERM, FDEP, FWC | PBCERM, FDEP, FWC, Volunteers |
| Water Quality Monitoring Network (FIU/SERC) | Status and trends of monitoring of water quality parameters to evaluate progress toward achieving/maintaining water quality standards and protecting/restoring living marine resources in South Florida coastal waters. 340+ sites in Florida, 35 of which are located in Biscayne Bay in southeast Florida. Discrete sampling locations from MDCWQMN. | 1991 | SFWMD, USEPA | FIU-SERC |
| The Reef Environmental Education Foundation (REEF) | Scuba divers and snorkelers collect information on marine fish populations using Rover Diver Survey method. | 1993 | DWCF, EODF, HF, RHGFF, KF, JEMF, MF, MML, NFWF, NC, NWP, NWF, OF, RFF, SS, TF, WSA, WSG | Volunteers |
| Broward County Marine Biological Monitoring Program (BCEPD) | Long-term fish and coral monitoring program to check relative health of the reef community habitats offshore of Broward County. | 1997 | BCEPD | BCEPD, NSUOC-NCRI |
| Bal Harbour Mitigation Monitoring Project | Long-term monitoring documenting benthic and fish assemblages on a limerock boulder and module reef with comparisons to adjacent natural reefs. Currently in year 8 of a 20 year monitoring plan. | 1999 | DERM | USACE |
| Biscayne Bay Submerged Aquatic Vegetation (SAV) Monitoring (DERM) | Annual assessment of SAV at 100 stations within central and southern Biscayne Bay and 11 "fixed' stations within central and northern Biscayne Bay. | 1999 | SFWMD, DERM | SFWMD, FDEP |
| Southeast Florida Coral Reef Evaluation and Monitoring Program (SECREMP) | Long-term monitoring of benthos within southeast Florida; northern Miami-Dade through Martin Counties. | 2003 | NOAA, FDEP, FWC, NSUOC-NCRI | FDEP, FWC, NSUOC-NCRI |
| Palm Beach County Reef Rescue Monitoring (PBCRR) | Monitoring algal blooms, coral condition and *Acropora* spp. locations. Area of monitoring is between points shown on Figure 5.9. | 2003 | Various | Volunteers |
| Harbor Branch Oceanographic Institute Comparative Ecology of Harmful Algal Blooms (HBOI) | Track the spread of *Caulerpa brachypus* and better understand the role of nutrients in facilitating this invasion. | 2004 | Current: FWRI<br>2003-04: USEPA ECOHAB | FWRI, HBOI |
| Broward County Coastal Water Quality Monitoring Program (BCEPD/NSUOC) | Pilot coastal water quality monitoring program collecting monthly surface and bottom water samples. | 2005 | BCEPD | BCEPD, NSUOC |
| Florida Reef Resilience Program Disturbance Response Monitoring (FRRP/ TNC) | Disturbance response monitoring to improve understanding of reef health and to identify factors that influence the long-term resilience of corals, reefs and the marine ecosystem. | 2005 | FDEP, TNC and Others | TNC, FDEP, GBRMPA, NOAA and others |
| Florida Area Coastal Environmental Initiative (NOAA/FACE) | Extensively measure and quantify a variety of known nutrient sources for comparison with levels of anthropogenic quantities delivered to the coastal ocean via inlets, outfalls and other routes in southeast Florida. | 2006 | BC, CoH, CoBR, MDWSD, NOAA, SCRWTDB | NOAA, EPA, USACE, FDEP, USGS, FWC and others |
| Florida Fish and Wildlife Conservation Commission (FWC) | Population dynamics of gray snapper and snook; monitoring diversity and spawning locations of recreational fisheries species, sea temperatures, frequency and severity of upwellings. | 2006 | FWC | FWC |
| Baseline Limerock Boulder Reef Monitoring | Evaluation of benthic and fish assemblages on five multi-layered limerock boulder reefs throughout Miami-Dade County | 2006 | DERM, FWC | FWC |

BC -- Broward County
BCEPD -- Broward County Environmental Protection Department
CoBR -- City of Boca Raton
CoH -- City of Hollywood
DERM -- Miami-Dade County Department of Environmental Resource Management
DWCF -- Disney Wildlife Conservation Fund
ECOHAB -- Ecology and Oceanography of Harmful Algal Blooms
EODF -- Elizabeth Ordway Dunn Foundation
EPA -- Environmental Protection Agency
FDEP -- Florida Department of Environmental Protection
FIU -- Florida International University
FWC -- Florida Fish and Wildlife Conservation Commission
FWRI -- Florida Fish and Wildlife Research Institute
GBRMPA -- Great Barrier Reef Marine Park Authority
HBOI -- Harbor Branch Oceanographic Institute
HF -- The Henry Foundation
JEMF -- The J. Edward Mahoney Foundation
KF -- The Korein Foundation
MDWSD -- Miami-Dade Water and Sewer Department
MF -- The Meyer Foundation
MML -- Mote Marine Laboratory
NSUOC -- Nova Southeastern University Oceanographic Center
NC -- The Nielsen Compan
NCRI -- National Coral Reef Institute
NFWF -- National Fish and Wildlife Foundation
NOAA -- National Oceanic and Atmospheric Administration
NWF -- Norcross Wildlife Foundation
NWP -- New World Publications
OF -- The Ocean Foundation
PBCERM -- Palm Beach County Department of Environmental Resources Management
RFF -- The Russell Family Foundation
RHGFF -- Robert J. and Helen H. Glaser Family Foundation
SCRWTDB -- South Central Regional Wastewater Treatment and Disposal Board
SERC -- Southeast Environmental Research Center
SFWMD -- South Florida Water Management District
SS -- Seaspace
TF -- Triad Foundation
TNC -- The Nature Conservancy
USACE -- United States Army Corps of Engineers
USGS -- United States Geological Survey
WSA -- Washington Scuba Alliance
WSG -- Washington Sea Grant

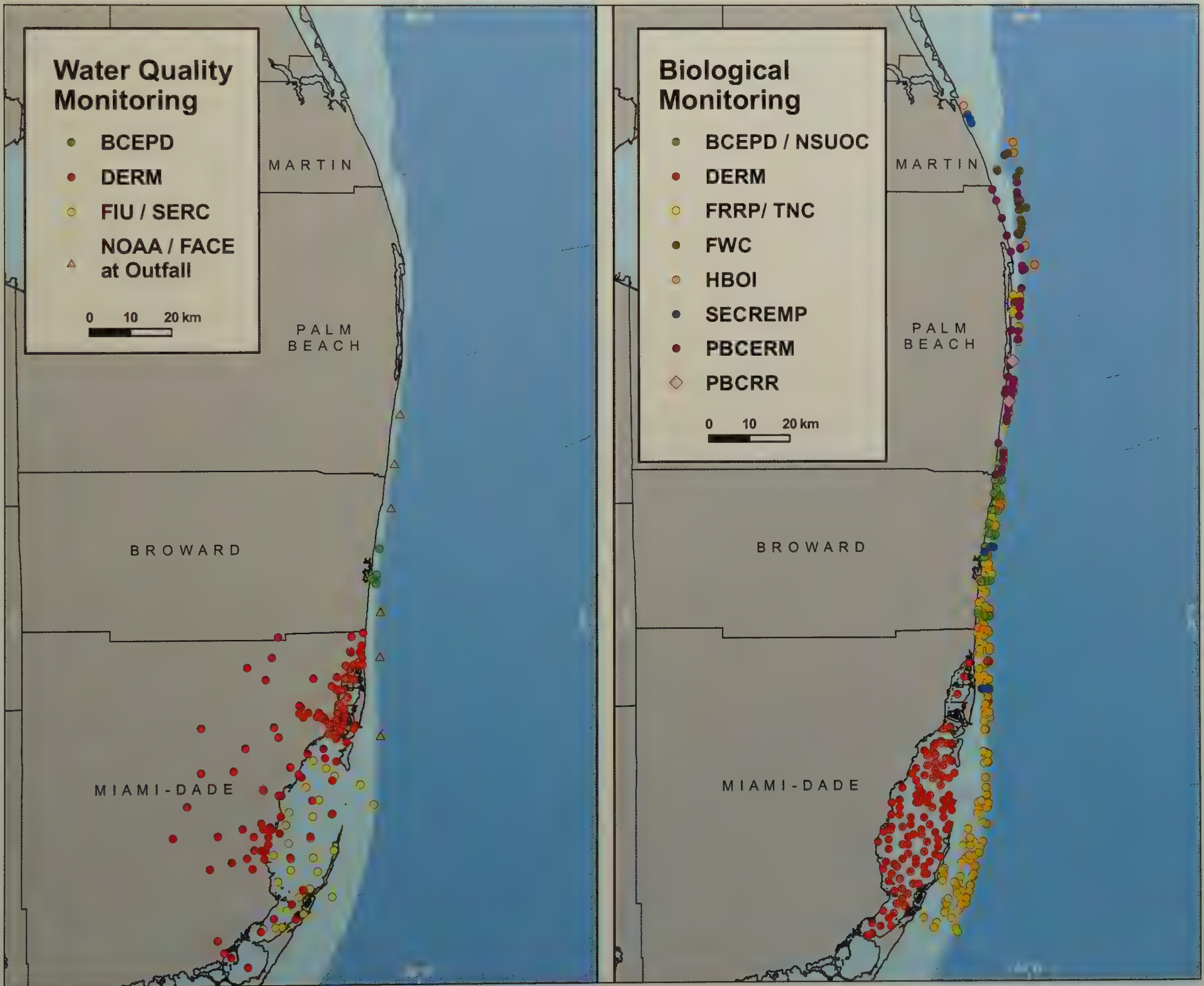

Water Quality Monitoring
BCEPD
DERM
FIU / SERC
NOAA / FACE at Outfall
0 10 20 km
MARTIN
PALM BEACH
BROWARD
MIAMI-DADE
Biological Monitoring
BCEPD / NSUOC
DERM
FRRP/ TNC
FWC
HBOI
SECREMP
PBCERM
PBCRR
0 10 20 km
MARTIN
PALM BEACH
BROWARD
MIAMI-DADE

*Figure 5.9. A map of the monitoring locations across southeast Florida discussed in this chapter. The PBCRR project samples the area between the two points shown. Map: K. Buja.*

## WATER QUALITY AND OCEANOGRAPHIC CONDITIONS

Land-based sources of pollution and poor water quality are recognized as a key threat to marine resources in southeast Florida (Florida Department of Environmental Protection, 2004). However, there are no regional, comprehensive, coordinated or long-term water quality monitoring programs in southeast Florida. The information that follows summarizes the limited activities in place, and new initiatives in development.

### Water Quality Monitoring Across the Southeast Florida Region

Coral reefs off southeast Florida have experienced unprecedented blooms of macroalgae and cyanobacteria during the past two decades. Beginning in 1989, extensive blooms of *Codium isthmocladum* impacted deep (27-45 m) reefs off northern Broward County and Palm Beach County. Sea Grant-funded monitoring studies established that these blooms were adapted to low light levels and developed seasonally in the late spring and summer (Lapointe, 1997). Water column sampling for dissolved inorganic nutrients and tissue analysis for carbon:nitrogen:phosphorus (C:N:P) ratios further indicated that the *C. isthmocladum* blooms were related to nutrient enrichment (nitrogen and phosphorus) from both natural and anthropogenic land-based sources (Lapointe et al., 2005a).

Studies assessing stable nitrogen isotopes in macroalgal tissue were conducted at a network of shallow, mid-depth and deep reefs in Palm Beach and northern Broward counties in 2001 to address possible linkages of macroalgal blooms with land-based nutrient source (Lapointe et al., 2005b). This study, which compared a dry season without upwelling versus a wet season with strong upwelling, indicated that land-based sources of nitrogen enrichment, including sewage outfalls, were a more important source of nitrogen enrichment than natural upwelling to blooms of *Codium isthmocladum* and *Caulerpa* spp. During this study, scientists discovered the invasive *Caulerpa brachypus f. parvifolia* (Pacific native) overgrowing deep reef communities in northern Palm Beach County.

To track the spread of *Caulerpa brachypus* and better understand the role of nutrients in facilitating *C. brachypus* proliferations, the Florida Fish and Wildlife Research Institute (FWRI) and Harbor Branch Oceanographic Institution (HBOI) initiated an expanded reef monitoring program in a study area extending from northern Dade County to St. Lucie County in 2004. This monitoring program initially included 88 randomly selected reef sites throughout the study area that were stratified into shallow, mid-depth, and deep reefs and sampled in the wet (June-October) and dry (November-May) seasons. At each site, replicate samples of near bottom water were collected for determination of dissolved inorganic and organic nitrogen and phosphorus concentrations. Abundant macroalgae from each site were also collected for determination of C:N:P ratios and stable nitrogen isotopes. Water samples were collected from various natural (rainfall and upwelling) and anthropogenic (sewage outfalls and inlet discharges) nutrient sources for determination of nutrient concentrations and stable nitrogen isotope ratios. Divers also collected underwater digital video imagery from replicate transects to quantify benthic biota, especially blooms of macroalgae and the cyanobacterium *Lyngbya* spp. Shortly after initiating this monitoring effort in August 2004, hurricanes Frances and Jeanne made landfall in northern Palm Beach County and temporarily removed the invasive *C. brachypus* blooms (Lapointe et al., 2006).

On relatively oligotrophic coral reefs in Dade and Broward counties off southeast Florida, blooms of the phaeophyte *Dictyota* spp., the calcareous chlorophyte *Halimeda* spp. and the cyanobacterium *Lyngbya* spp. have developed. On more northern coral reefs off Palm Beach County, blooms of the chlorophytes *Codium* spp. and *Caulerpa* spp. have recurred since 1990. Monitoring of the water column for dissolved inorganic and organic nutrients and algal tissue for C:N:P ratios suggests that the observed taxonomic shifts in these macroalgal blooms are related to N:P availability. For example, relatively high tissue N:P ratios (35:1-70:1) occur in Dade and Broward counties compared to lower values in Palm Beach County (33:1). These differences in N:P ratio result from both natural patterns in geological substrata as well as anthropogenic nutrient enrichment of the watershed.

### The Florida Area Coastal Environment Program

The FACE program is an ongoing, long-term effort to gather a broad range of data needed for understanding the coastal environment, for evaluating potential anthropogenic impacts, for guidance in the operation and development of water and sewer infrastructure, and for the formulation of science-based regulation. FACE is a focused measurement and analysis program designed to address the scientific aspects of societal questions of pressing importance in the general areas of wastewater discharge and water provision. FACE program data are also of substantial use in dredged material discharge studies (McArthur et al., 2006). In the longer term, the FACE program may evolve into a unified water study program including not only coastal ocean water but fresh waters as well for a "unified" study of south Florida waters.

There are multiple routes whereby human generated substances may find their way to coral reef ecosystems. Agricultural nutrients, septic tank leakages and storm water discharges may find their way to coastal ocean coral reef sites via inlets, cuts or even groundwater discharges. Secondarily treated wastewater effluent outfalls are also a source of nutrients and other pollutants to the coastal ocean. Nature is a prospective supplier of significant amounts of nutrients via upwelled oceanic water. In the Florida Keys (Leichter et al., 2003), internal bores have been suggested as a mechanism for the transport of nutrients from nearby nutrient rich deeper ocean water. Also in the Florida Keys, Hitchcock et al. (2005) have suggested that transport of deeper waters may occur with Gulf Stream eddies. Some (Lapointe, 1997) have suggested that anthropogenic nutrients are related to algal growth on the reefs, while others (Szmant, 2002) have suggested alternate causes. Long-term reef observations carried out using accepted scientific protocols at multiple locations are needed to understand the natural variation in the populations of algae and other reef species.

The FACE program's primary area of observations includes the coastal ocean off southeast Florida as well as adjacent waters and groundwater. The program includes nutrient, stable isotope, sediment, algal, coral, physical oceanographic, chemical, meteorological, genetic and microbiological measurements. Atmospheric input measurements are also planned. Related/cooperating programs include the Integrated Coral Observation System (ICON) and the Florida Bay measurement program. Existing and planned measurement systems include long-term *in situ* sensors, large-ship borne sensors and regular sampling from small ships. Continuous temperature data gathered at several sites during 2005 and 2006 off Miami-Dade, Broward and Palm Beach counties have shown the existence of correlated temperature decreases in ambient water temperatures. Comparison of 2005 and 2006 data has shown that while significant appearances of cold water occur during hurricane passage, significant cold water appearances are seen to occur in the absence of local meteorological forcing. The FACE fact sheet (NOAA Keynotes, 2006) displays some of the temperature data. More FACE data will become available in subsequent years.

### Broward County

Broward County's Environmental Monitoring Division, Environmental Protection Department (EPD) implemented a pilot coastal water quality monitoring program in December 2005. This initial effort targets Port Everglades and adjacent areas on the north and south since Port Everglades represents one of the major inputs to Broward County's coastal waters. Surface and bottom water samples are collected from four stations at Port Everglades and three stations where the Biological Resources Division and EPD conduct coral monitoring activities and/or has thermographs. Efforts will be made to sample on a monthly basis. Samples are analyzed for chlorophyll, turbidity, and nutrients including: ammonium ($NH_4$), nitrate ($NO_3$), nitrite ($NO_2$), total dissolved nitrogen (TDN), total nitrogen (TN), soluble reactive phosphate (SRP), total dissolved phosphorus (TDP), total phosphorus (TP), silicate ($Si(OH)_4$), dissolved organic carbon (DOC) and total organic carbon (TOC). In addition to water samples, secchi depth is measured, field conditions noted and vertical profiles of temperature, depth, chlorophyll a ($Chl_a$), dissolved oxygen (DO), pH, specific conductivity and turbidity are collected at each site using a YSI sonde. EPD plans to expand monitoring efforts to ten stations by the end of 2008.

### Palm Beach County

Palm Beach County's Department of Environmental Resources Management (ERM) is in the process of implementing a pilot coastal water quality monitoring program. The initial effort will target wastewater outfalls and the Lake Worth Inlet. Discharges from these sources represent the major contributors of freshwater effluent into Palm Beach County's coastal waters. Surface and bottom water samples will be collected from ten stations, the Lake Worth Inlet and nine additional stations, where ERM conducts reef monitoring activities. Samples will be analyzed for chlorophyll, turbidity, and nutrients including $NH_4$, $NO_3$, $NO_2$, TDN, TN, TP, $Si(OH)_4$, DOC and TOC. In addition to water samples, secchi depth will be measured, field conditions noted and vertical profiles of temperature, $Chl_a$, DO, pH, conductivity and turbidity will be collected at each site using a Hydrolab. Consideration is being given to expanding monitoring through a joint effort with NOAA.

### St. Lucie State Park

The inshore reef associated with St. Lucie Inlet Preserve State Park is unique in terms of its setting in the coastal landscape, with open ocean to the east, undeveloped barrier island dunes and mangrove swamps to the west (a state park), and a maintained inlet (St. Lucie Inlet) and major outfall for surface water (St. Lucie River and Indian River Lagoon) to the north. These regional features shape the hydrodynamics and water quality along the 7 km reef tract, creating an obvious zonation of effects. The northern half of the reef is predominantly worm rock (*Phragmatopoma* spp.) with very few hard corals due to the influence of the surface water input through the inlet. The watershed of the St. Lucie River has tripled in size during the past century, including a connection to Lake Okeechobee. The water quality in the reef's northern half is characterized by high levels of total suspended solids (TSS), color (tannins) and certain nutrients (e.g., nitrogen and phosphorus), and wide fluctuations in salinity, making conditions suitable for worm rock growth. The reef's southern half is influenced greatly by oceanic waters with acute changes in water quality during periods of high flow from the inlet as longshore transport brings estuarine water southward. During 2006, the Florida Fish and Wildlife Conservation Commission held a symposium for the St. Lucie reef, including a panel discussion regarding the need for a unique water quality monitoring effort addressing these issues and the influence of water quality on benthic organisms and fish communities.

## BENTHIC HABITATS

### The Southeast Florida Coral Reef Evaluation and Monitoring Project

Since 1996, the Coral Reef Evaluation and Monitoring Project (CREMP) has documented changes in reef resources throughout the Florida reef tract from the northern Florida Keys to the Dry Tortugas. In 2003, CREMP was further expanded to include 10 sites offshore of southeast Florida in Miami-Dade (three sites), Broward (four sites) and Palm Beach (three sites) counties. This CREMP expansion, named the Southeast Florida Coral Reef Evaluation and Monitoring Project (SECREMP) was expanded again in 2006 with the addition of three sites in Martin County. Usually, monitoring efforts along the southeast coast are associated with environmental impact and mitigation studies at specific sites (dredging, ship groundings, pipeline and cable deployments and beach renourishment). Monitoring efforts that are part of marine construction activities are generally of limited duration (1-3 years) and focus on specific project areas. However, monitoring conducted by SECREMP is not tied to other activities and was designed to be a region-wide, long-term project that fills gaps in monitoring of coral reef ecosystems as part of a nation-wide effort. SECREMP complements the goals of the

National Coral Reef Ecosystem Monitoring Program (NCREMP) to monitor a minimum suite of parameters at sites in the network.

SECREMP follows the established Florida Keys CREMP protocols (Johnson et al., 2008). Monitoring consists of four stations at each of 12 sites where, at each station, a stony coral species inventory, video transect and bio-eroding sponge survey are conducted. The stony coral species inventory provides a species list for each station and includes longspine sea urchin, *Diadema antillarum*, abundance and information on diseased and bleached stony coral colonies. The video transects are used to determine the cover of stony coral species, gorgonians, sponges and macroalgae. A thirteenth monitoring site in Martin County (MC3) was established in 2006 with a unique purpose. Forty-nine individual coral colonies, representing six species were mapped within this site, and images of the colonies will be used to estimate growth and track colony condition. In 2007, benthic temperature data loggers were deployed at all SECREMP sites.

*Results and Discussion*

With four years of data (2003-2006) the SECREMP sites indicate that, in general ,there appears to be little change in the status of the southeast Florida reef system. The stony coral species inventory shows no trend in species richness changes within the 10 sites sampled since 2003 (excludes Martin County), except the nearshore site in Palm Beach County (PB1) which was partially covered in sand in 2005 and 2006 (Figure 5.10). There is a trend towards reduced richness in the northern part of the region with Miami-Dade County (21 species) and Broward County (24 species) having more species than Palm Beach County (17 species) and Martin County (eight species). The three most common hard coral species were *Montastraea cavernosa*, *Siderastrea siderea* and *Porites astreoides*, and they were found in all four counties and at least 12 sites (Gilliam, 2007).

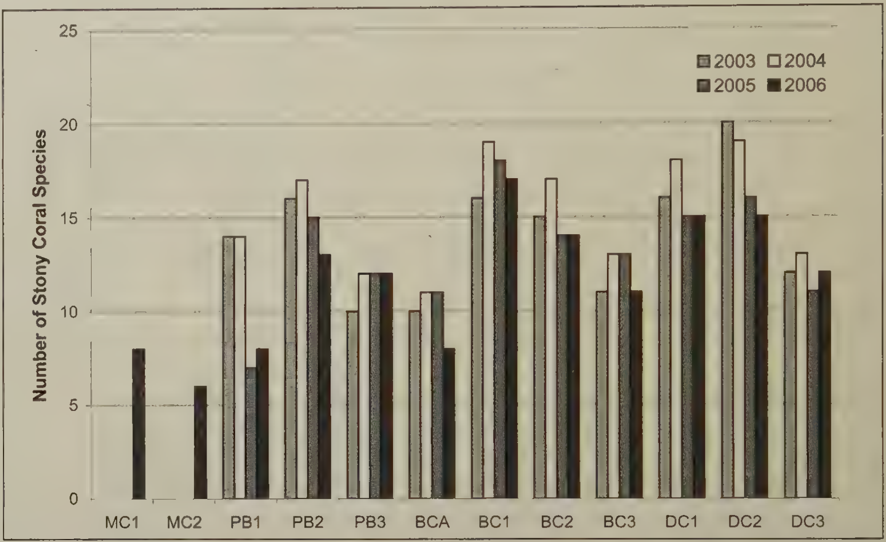


*Figure 5.10. Number of stony coral species identified within each of the SECREMP sites 2003-2006 (MC = Martin County, PB = Palm Beach County, BC = Broward County, DC = Miami-Dade County). MC sites were not established until 2006. Source: SECREMP, unpub. data.*

There also do not appear to be any consistent temporal changes in functional group cover between 2003 and 2006. Octocorals consistently contribute most to community cover in Miami-Dade, Broward and Palm Beach Counties followed by macroalgae and sponges (Table 5.3); while in Martin County, with only 1 year of data, macroalgae contributes most to cover. Stony coral cover in the region is generally between 0.5% and 2.5%. Two Broward sites (BC1 and BCA) were specifically included in the project to capture information on reef areas with unusually high stony coral cover. BC1 is within an area that has a high density of larger (>1 m diameter) *M. cavernosa*, *Montastraea faveolata* and *Colpophyllia natans* colonies and a stony coral cover of nearly 13%. BCA was specifically added to the project for the purpose of monitoring one of the unique *Acropora cervicornis* patches that occur offshore Broward County. This is especially important with the recent federal listing of *A. cervicornis* as a threatened species. *A. cervicornis* cover at BCA increased slightly from 31% in 2003 to 39% in 2005 but decreased in 2006 to 25%. This reduced *A. cervicornis* cover in 2006 was also identified during the Broward County Marine Biological Monitoring Project (Gilliam et al. 2007). Through fragmentation, *A. cervicornis* patches are dynamic in live tissue cover and boundaries. Increased effort is planned to map patch boundaries and track cover and condition beyond the permanent stations.

### Broward County Marine Biological Monitoring Program

The present configuration of the Broward County Environmental Protection Department's Marine Biological Monitoring Program began in 1997 with the installation and initial monitoring of 18 offshore reef community transect sites. The sites were distributed such that there were three offshore of each of the following municipalities (from south to north): the City of Hollywood Beach, John U. Lloyd Beach State Park, the City of Fort Lauderdale, the Town of Lauderdale-By-The-Sea, The Town of Hillsboro Beach and the City of Deerfield Beach. Each latitudinal location had one permanent transect on each of the three reef tracts. These original 18 sites were established to initiate a long-term monitoring program to check relative health of the reef community habitats offshore of Broward County. Additionally, in anticipation of reef monitoring requirements that would become part of permits issued for the Broward County Shore Protection Project, it was proposed to federal and state agencies that monitoring of these sites become part of the Biological Monitoring Plan for the Project. Subsequent review by those agencies prompted the installation of five additional transect sites in 2001 and an additional two transect sites in 2004 for a total of 25 sites. The sites each have a 20 m belt-quadrat transect (30 $m^2$ total area) and sediment collector ringstands, each containing three replicate sediment traps. Sediment traps are changed out and analyzed every 60 days for sediment fallout rate calculation ($mg/cm^2/day$) and grain-size distribution, while the transects are visited annually during the months of September and October. Transects are examined for stony coral species density (colonies/$m^2$), diversity and evenness (Shannon indices), percent of live coral cover, and density of octocorals and sponges. In conjunction with the coral surveys, fish populations are assessed annually following methodology published by Bohnsack and Bannerot (1986) and Bortone et al. (1989). The 18 original sites have been monitored for ten years, 23 sites have been monitored for six years, and all 25 sites have been monitored for four years.

*Table 5.3. Functional group percent cover (mean and range) within each of the SECREMP sites 2003-2006 (Broward County has four sites, Miami-Dade County has three sites and Palm Beach County has three sites. Martin County has two sites, which were established in 2006. Source: Gilliam, 2007; http://www.dep.state.fl.us/coastal/programs/coral/reports/.*

| | STONY CORALS | | OCTOCORALS | | SPONGES | | MACROALGAE | |
|---|---|---|---|---|---|---|---|---|
| | *Mean* | *Range* | *Mean* | *Range* | *Mean* | *Range* | *Mean* | *Range* |
| **Broward Co.** | | | | | | | | |
| 2003 | 11.2 | 31.7 - 0.3 | 7.2 | 13.5 - 2.3 | 1.9 | 2.8 - 0.3 | 1.9 | 3.7 - 0.3 |
| 2004 | 13.1 | 39.6 - 0.4 | 7.8 | 16.0 - 2.0 | 2.4 | 3.6 - 0.5 | 1.7 | 4.0 - 1.0 |
| 2005 | 13.3 | 39.9 - 0.3 | 8.9 | 17.9 - 1.5 | 2.9 | 4.2 - 0.4 | 6.5 | 11.9 - 1.8 |
| 2006 | 9.8 | 25.4 - 0.4 | 7.1 | 14.1 - 1.4 | 3.5 | 5.1 - 1.1 | 15.4 | 34.6 - 6.8 |
| **Miami-Dade Co.** | | | | | | | | |
| 2003 | 1.1 | 2.4 - 0.2 | 12 | 15.5 - 5.9 | 3.2 | 5.1 - 0.9 | 8.5 | 13.3 - 2.3 |
| 2004 | 1.1 | 2.6 - 0.2 | 10.4 | 12.3 - 7.3 | 2.6 | 4.0 - 1.1 | 12.9 | 31.4 - 3.3 |
| 2005 | 1.2 | 2.8 - 0.3 | 13 | 15.9 - 8.0 | 2.9 | 4.0 - 1.5 | 5.7 | 12.8 - 1.8 |
| 2006 | 1.3 | 3.0 - 0.2 | 10.1 | 12.2 - 7.7 | 3.2 | 4.8 - 2.1 | 15.7 | 20.5 - 10.3 |
| **Palm Beach Co.** | | | | | | | | |
| 2003 | 1.3 | 1.8 - 1.0 | 20.1 | 30.3 - 2.7 | 8.1 | 10.5 - 3.5 | 0.1 | 0.3 - 0.0 |
| 2004 | 1.2 | 1.8 - 0.9 | 21.3 | 31.2 - 2.9 | 7.6 | 9.8 - 4.2 | 1.4 | 2.5 - 0.3 |
| 2005 | 0.9 | 1.6 - 0.1 | 17.5 | 27.5 - 0.0 | 4.2 | 9.5 - 0.2 | 1 | 1.5 - 0.7 |
| 2006 | 1 | 1.8 -0.4 | 14.3 | 23.4 - 0.0 | 4.8 | 9.3 - 0.1 | 7.9 | 12.4 - 3.9 |
| **Martin County** | | | | | | | | |
| 2006 | 1.3 | 1.6 - 1.0 | 0 | 0.0 - 0.0 | 1.8 | 2.6 - 1.1 | 38.3 | 42.0 - 34.5 |

Average coral cover for all 25 sites in 2006 was 4.2% (±7.7%) and the average coral cover for the original 18 sites (10 year average) was 1.7% (±1.1%). Included in the 2006 figure are three very high coral cover sites (34.0%, 15.8% and 19.2%) located on the first (inner) reef tract offshore of Fort Lauderdale. If these values are removed from the 2006 calculation, live coral cover (22 sites) was 1.6% (±1.2%), a value not significantly different from the 10-year average for the original 18 sites. Among the 23 sites monitored since 2001, mean coral density, stony coral cover and mean octocoral density have not significantly changed (Gilliam et al., 2007; Gilliam et al., in prep.). Results of multivariate statistical analysis indicate that the stony coral assemblages offshore of Broward County have changed little from 1997 to 2006. The analysis has also shown that the coral communities within the third (outer) reef and second (middle) reef sites have greater similarity than the sites within the first reef. The 2006 survey for fishes revealed that significantly fewer fish were counted on the first reef compared to either the second reef or the third reef. Haemulidae (grunts) was the predominant family on the first reef, Labridae (wrasses and damselfishes) and Carangidae (jacks) were predominant on the second reef, and fish in the Labridae family dominated the third reef. Sediment rate analysis since 1997 has consistently shown that the first reef sites exhibit a statistically significant higher sedimentation rate than both the second and third reefs and that the second reef sedimentation rate is significantly higher that the third reef rate. Additionally, there appears to be a seasonal trend with the highest annual rates of sedimentation occurring during the late fall/early winter.

### *Palm Beach County Monitoring*

Characterization of benthic assemblages in Palm Beach County is ongoing for inshore, artificial, and some offshore reefs associated with beach nourishment projects (Continental Shelf Associates Inc., 1983; Continental Shelf Associates Inc., 1985; Palm Beach County Department of Environmental Resources Management, 1993; Palm Beach County Department of Environmental Resources Management, 1994; Coastal Planning & Engineering Inc., 2007) and for artificial reefs (Continental Shelf Associates Inc., 2006). The Palm Beach County Reef Research Team has performed routine monitoring and assessment of benthic communities on artificial reefs for 10 years and initiated work on the natural, deeper reefs in 2006. Monitoring methods include use of photoquadrats with post-processing of point counts (Palm Beach County Reef Research Team, 2004), videography with post-processing of line transects (Continental Shelf Associates Inc., 2006), in-water quadrat assessment with videography of line transects (Coastal Planning & Engineering Inc., 2007) and line intercept transects (Phipps, pers. comm.). Palm Beach County Reef Rescue, a volunteer, non-profit group of divers, has been monitoring the occurrence of algal blooms in southern Palm Beach County for several years (Tichenor, 2003; 2004a; 2004b; 2005).

Nearshore shallow (<4 m) reef habitats are dynamic and vary widely in benthic cover. Macroinfaunal communities have high species richness and diversity with 133 species representing 13 phyla counted in one study (Continental Shelf Associates Inc., 1983). Species numbers of epifaunal invertebrates range from 60 for Ocean Ridge to 25 for Jupiter Island (Continental Shelf Associates Inc., 1985; Palm Beach County Department of Environmental Resources Management, 1994). Macroalgal coverage is typified by low-growth plants, generally filamentous or encrusting forms representing approximately 23 to 31 species countywide (Palm Beach County Department of Environmental Resources Management , 1994). Worm rock (*Phragmatopoma* spp.) coverage averaged 30% countywide (Vare, 1991). *Siderastrea radians* is the most frequently encountered scleractinian coral, but five species of hard coral with approximately 5% coverage represented the nearshore reefs (Continental Shelf Associates Inc., 1985). Nearshore, softbottom benthic macroinfaunal samples yielded 33 species of macroinvertebrates dominated by polychaetes (Palm Beach County Department of Environmental Resources Management, 1994).

Offshore reefs in Palm Beach County are dominated by octocorals (Gorgonacea) and sponges (Porifera; Continental Shelf Associates Inc. 1985; Palm Beach County Department of Environmental Resources Management 1994). Goldberg (1970) identified 39 species of octocorals and 27 species of hermatypic corals. Forty species of sponge were recorded in North Boca Raton and on offshore reefs (Continental Shelf Associates Inc., 1985).

Artificial reefs constructed from concrete can develop complex benthic communities with diverse Scleractinian and octocoral assemblages. Hydroids, specifically the algae hydroid (*Thyroscyphus ramosus*), can be the principal colonizer of artificial reefs. Compared to natural reefs, artificial reefs have less algal diversity and fewer scleractinian and octocoral species (Palm Beach County Reef Research Team, 2004).

## ASSOCIATED BIOLOGICAL COMMUNITIES

### FISH

Three main reef tracts run roughly parallel to shore in Dade and Broward Counties while in Palm Beach and Martin Counties the inner and middle tracts disappear. The outer reef tract continues to run parallel to shore until the Lake Worth Inlet in Palm Beach County, where it terminates. A series of shore-parallel ridges continue northward into Martin County (Banks et al., 2007). In Miami-Dade, Broward, and most of Palm Beach Counties the third (outer) reef tract lies 1.5-2.5 km offshore, but the distance of the ridges increases to 3 km in north Palm Beach County and up to 9-13 km in northern Martin County.

Numerous stationary and roving visual fish surveys have been performed by SCUBA divers to assess reef fish populations (<30 m depth) in the southeast Florida region. In Broward County, an additional 20+ hours of ROV surveys have been completed between the depths of 50-200 m. Broward County conducts, on average, 300 surveys annually and has recorded 300 species in <30 m depth (Ferro et al., 2005; Bryan 2006). Since its inception in 1993, the REEF database (REEF, 2007) has received over 3,500 surveys for Palm Beach County and recorded a total of 404 species from 108 sites. Fish counts by Palm Beach County Environmental Resources Management and Palm Beach County Reef Research Team (PBCRRT) on both natural and artificial sites have recorded 193 species representing 48 families (Palm Beach County Reef Research Team 2004). In Martin County, the Florida Fish & Wildlife Conservation Commission (FWC) completed 101 surveys in 2006. Only fish >10cm in length were counted, but a total of 118 species were observed on four sites between 15-25 m depth (McDevitt, pers. comm.). Within the St. Lucie Inlet Preserve State Park, FWC has recorded 244 species including the endemic striped croaker, *Bairdiella sanctaeluciae* (Beal, pers., comm.). For southern Miami-Dade County, a study spanning more than 25 years of fishery-dependent and fishery-independent data has documented 318 fish species in BNP (Ault et al., 2001).

In general, species composition resembles other Caribbean and tropical Atlantic sites with an increasing abundance of temperate species (e.g., pigfish, *Orthopristis chrysoptera*) on reefs of the northern southeast Florida region. The 20 most commonly observed fish species in the southeast Florida region identified in the REEF database are listed in Table 5.4. There are differences in assemblage structure among the reef tracts, with increasing fish abundance and species richness moving from inshore to offshore reefs. Grunts (Haemulidae) are abundant on all reef tracts but predominate on inshore reefs (<12 m depth) and some estuaries (e.g., Lake Worth Lagoon) in Palm Beach County. Juvenile populations alone can comprise 60-90% of the total assemblage on inshore reefs (Ferro et al., 2005). On deeper reefs, wrasses (Labridae), surgeon and doctor fishes (Acanthuridae) and damselfish (Pomacentridae) become more abundant (Ferro et al. 2005). Most likely due to high fishing pressure, large groupers (Serranidae) and snappers (Lutjanidae) are relatively rare throughout the southeast Florida region (Ault et al., 2001; Ferro et al., 2005). For example, in Broward County, only two of the 242 grouper and 219 of the 718 snapper recorded during the four year survey period were of minimum legal size (Ferro et al., 2005).

Numerous artificial reefs have been deployed in the southeast Florida region. Artificial reefs consist of ships, limestone boulders, concrete demolition pieces and/or prefabricated structures, and they have been deployed for habitat and fishery enhancement as well as for experimental studies (Sherman et al., 1999; Sherman et al., 2001; Arena et al., 2002; Arena et al., 2007). A cumulative review of data collected by the PBCRRT from 1997 to 2003 shows that fish assemblages cluster into groups based primarily on depth (<9 versus >18 m) and secondarily on structural material (Harkanson, in prep.). Derelict ships can have higher species richness and abundance than neighboring reefs with species-specific differences in composition or aggregation size (Arena et al., 2007). Ships that have been deployed in 50-120 m depth have different assemblages of fishes than shallower vessel-reefs (Bryan, 2006). For example, the abundance of herbivorous species is higher on shallower, sunken artificial reefs, while the presence of planktivorous species is greater on deeper ones (Beal, pers. comm.; Arena et al., 2002; Bryan, 2006).

## FISHERIES

Both recreational and commercial fishing occur in southeast Florida waters. Recreational fishers of southeast Florida counties land more than 200 species (Johnson et al., 2007) and account for roughly 20% of statewide recreational fishing licenses indicating a significant local contribution to fishing pressure. Visitors to southeast Florida also contribute to this fishing demand as many tourists wish to experience the “Fishing Capital of the World”, as the state of Florida promotes itself (Florida Fish and Wildlife Conservation Commission, 2007). Along the reef tract, the most commonly targeted species are members of the snapper-grouper complex, including snappers (Lutjanids), groupers (Serranids), grunts (Haemulids) and porgies (Sparids). Commercial fisheries in southeast Florida target reef and pelagic fishes, spiny lobster (*Panulirus argus*), stone crab (Menippe mercenaria), blue crab (*Callinectes sapidus*), pink shrimp (*Farfantepenaeus* spp.) and ballyhoo (*Hemiramphus brasiliensis*).

*Table 5.4. The 20 most commonly observed fish species on southeast Florida reefs according to the REEF database. Frequency of sightings is compiled from 6,271 surveys completed between 1993 and 2007. Source: REEF database, www.reef.org.*

| RANK | COMMON NAME | SPECIES | FAMILY | FREQUENCY OF SIGHTING (%)[1] |
|---|---|---|---|---|
| 1 | Porkfish | *Anisotremus virginicus* | Haemulidae | 84.0 |
| 2 | Bluehead wrasse | *Thalassoma bifasciatum* | Labridae | 83.5 |
| 3 | Sergeant major | *Abudefduf saxatilis* | Pomacentridae | 76.7 |
| 4 | French grunt | *Haemulon flavolineatum* | Haemulidae | 72.5 |
| 5 | Blue tang | *Acanthurus coeruleus* | Acanthuridae | 71.0 |
| 6 | Bicolor damselfish | *Pomacentrus partitus* | Pomacentridae | 66.4 |
| 7 | Ocean surgeon | *Acanthurus bahianus* | Acanthuridae | 65.7 |
| 8 | Doctorfish | *Acanthurus chirurgus* | Acanthuridae | 63.9 |
| 9 | Bluestriped grunt | *Hemulon sciurus* | Haemulidae | 63.5 |
| 10 | Spotted goatfish | *Pseudupeneus maculatus* | Mullidae | 60.2 |
| 11 | Stoplight parrotfish | *Sparisoma viride* | Scaridae | 60.0 |
| 12 | Tomtate | *Haemulon aurollneatum* | Haemulidae | 59.7 |
| 13 | Redband parrotfish | *Sparisoma aurofrenatum* | Scaridae | 59.5 |
| 14 | Bar jack | *Caranx ruber* | Carangidae | 57.3 |
| 15 | French angelfish | *Pomacanthus paru* | Pomacanthidae | 56.8 |
| 16 | White grunt | *Haemulon plumieri* | Haemulidae | 56.6 |
| 17 | Spanish hogfish | *Bodianus rufus* | Labridae | 55.5 |
| 18 | Sharpnose puffer | *Canthigaster rostrata* | Tetraodontidae | 52.6 |
| 19 | Gray snapper | *Lutjanus griseus* | Lutjanidae | 50.9 |
| 20 | High hat | *Equetus acuminatus* | Sciaenidae | 49.7 |

[1] Frequency of Sighting = the number of dives in which the species was observed divided by the total number of dives completed.

Little information exists on the historical levels of fishery resources in the southeast Florida region. NOAA’s National Marine Fisheries Service classifies 11 species landed in southeast Florida as regionally overfished and 11 species as subject to overfishing, with some species in both categories (NMFS, 2005). These include grouper species: gag (*Mycteroperca microlepis*), black (*M. bonaci*), red (*Epinephelus morio*), snowy (*E. niveatus*), warsaw (*E. nigritus*), goliath (*E. itajara*) and Nassau (*E. striatus*), speckled hind (*E. drummondhayi*), and the red (*Lutjanus campechanus*) and vermilion snapper (*Rhomboplites aurorubens*). Fisheries for goliath and Nassau grouper and for queen conch (*Strombus gigas*) were closed in the 1990s and remain closed today, although the goliath grouper stock shows signs of recovering (Porch et al., 2003; Porch et al., 2006). This has prompted discussions about the possibility of re-opening the goliath grouper fishery.

In southeast Florida, Ferro et al. (2005) inventoried fishes associated with reefs in Broward County over four years and noted a general scarcity or absence of groupers and snappers. Although juvenile red grouper were frequently seen (n = 232 at 667 sites), only two were above legal minimum size. A total of 10 gag, yellowfin or scamp grouper were observed, but none were of legal size. No goliath or black grouper were recorded. Of the 718 snappers in six species that were recorded, only 219 (30%) were of legal size.

Johnson et al. (2007) assessed trends in recreational and commercial fisheries in the southeast Florida region from 1990-2000 and determined that recreational and commercial fisheries combined landed over 260 species of finfish and invertebrates. Total average annual landings were 21.4 million lbs. (range 17.7-26.9) and were composed of 62% recreational, 35% commercial and 3% headboat landings. Recreational landings included 27% reef fishes, 23% coastal migratory fishes and 50% offshore pelagic fishes. Commercial landings included 17% reef fishes, 43% coastal migratory fishes, 20% offshore pelagic fishes, and 20% invertebrate species. Headboat landings were 38% reef fishes, 30% coastal migratory fishes, and 32% offshore pelagic fishes. Total commercial landings declined 33% (9.3 to 6.2 million pounds) between 1990 and 2000, although total commercial landings of invertebrates increased from 0.6 to 2.3 million pounds, primarily because of increased catches of shrimp and blue crab.

Total finfish landings averaged 20.7 million pounds per year and declined significantly (22%) from 1990 through 2000. The recreational sector contributed 66% of the total reported finfish landings, followed by 31% from the commercial sector and 3% from the headboat sector. Total finfish landings varied without trend for the recreational sector, but declined significantly for both the commercial and headboat sectors (Figure 5.11). The net result was that the relative proportion of total finfish landings increased over time for the recreational sector, but declined for the commercial and headboat sectors (Figure 5.11). Average annual total recreational fishing effort was 4.2 million angler trips from 1990-2000.

Total reef fish landings in the southeast Florida region averaged 4.8 million pounds annually over the 11 year period and were composed of 68% recreational, 27% commercial and 5% headboat landings. Reef fishes represented 27% of total recreational landings, 38% of total commercial landings and 17% of headboat landings. Total reef fish landings varied without trend for the recreational fishery (mean = 3.27 million lbs/yr), but declined significantly for headboat and commercial fisheries. Headboat landings of reef fish, for example, declined 65% from 0.32 to 0.11 million pounds between 1990 and 2000 concomitant with a 48% reduction in the number of angler days fished, and from 1993 to 2000, a 60% decline in catch per unit effort (lbs/angler/day). Total commercial reef fish landings declined 55% from 1.9 to 0.8 million pounds over the study period. Research is needed to determine whether these declines are associated with reductions in fish populations or fishing effort, or to other possible causes.

INVERTEBRATES

Annual reported commercial invertebrate landings in the southeast Florida region averaged 1.6 million pounds between 1990 and 2006 (Figure 5.12). Four fisheries comprised over 80% of the invertebrates landed during that time span: spiny lobster (33%), stone crab claws (3.4%), blue crab (11%), and combined food and bait shrimp (36%). Both commercial landings of spiny lobster and stone crab claws declined significantly over the reporting period while blue crabs and combined shrimp exhibited no statistically significant landings trend.

Of the four principal fisheries, only spiny lobster has an intensive recreational fishery. From 1993-2002 the recreational harvest averaged approximately 0.47 million pounds annually (Sharp et al., 2005). By comparison, commercial landings averaged about 0.57 million pounds per year over the same reporting period. Of note is a significant increase in the landings of miscellaneous invertebrates such as squid, octopus, slipper lobster and sponges . The increased harvest of these species may be due to commercial fishers being displaced from other fisheries (e.g., enactment of Florida's net ban in 1995 or increased management restrictions in other fisheries).

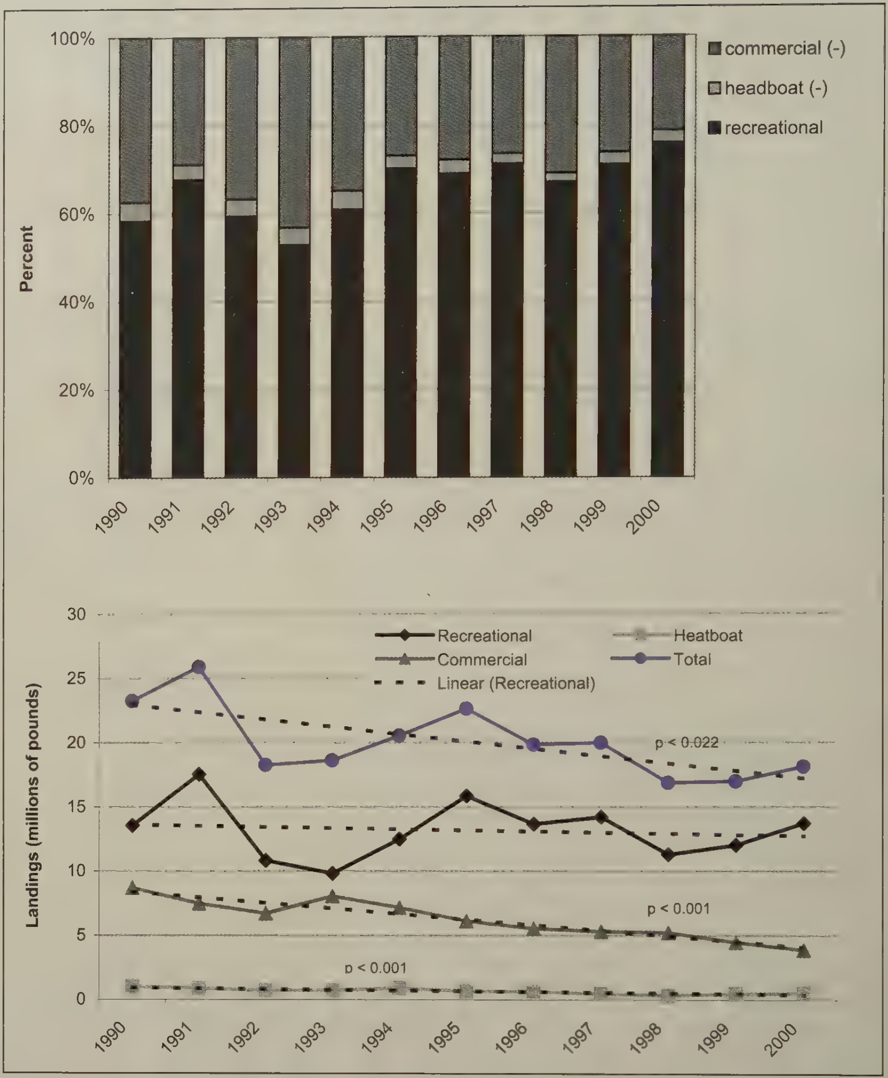


*Figure 5.11. Total annual finfish landings in the southeast Florida region by fishing sector (top) and by source (bottom). Dashed lines show significant (p < 0.05) linear trends. Source: Johnson et al., 2007.*

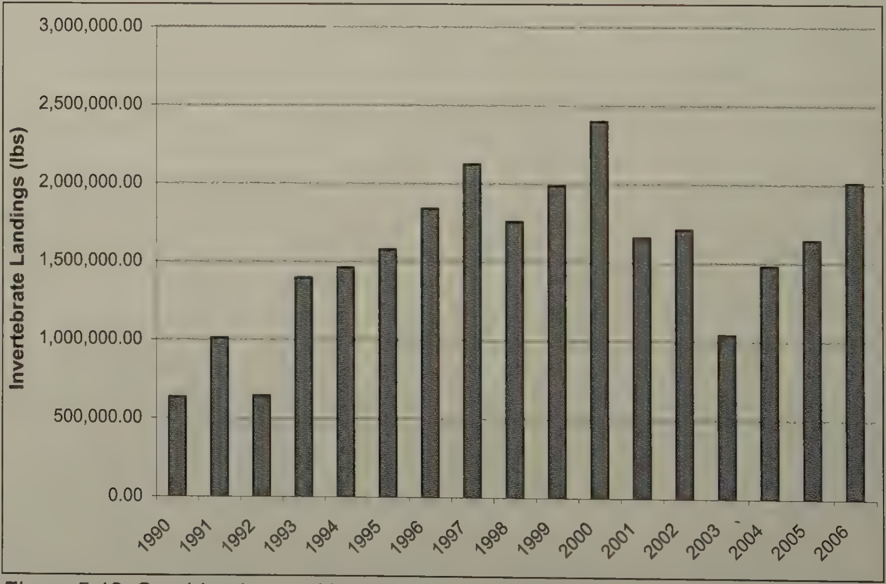


*Figure 5.12. Combined annual invertebrate landings for blue crab, stone crab claws, combined shrimp, lobster and miscellaneous invertebrates in the southeast Florida region from 1990 through 2006. Source: Johnson et al., 2007; FWC, unpub. data.*

## CURRENT CONSERVATION MANAGEMENT ACTIVITIES

Until 2004, coral reef conservation and management activities in southeast Florida were limited and activities in the region were led primarily by local county agencies. However, in 2003, with guidance from the U.S. Coral Reef Task Force (USCRTF), the Florida Department of Environmental Protection (FDEP) and the Florida Fish and Wildlife Conservation Commission coordinated the development of the Southeast Florida Coral Reef Initiative (SEFCRI). Linked to the goals and objectives of the USCRTF National Action Plan to Conserve Coral Reefs, SEFCRI is a local action strategy (LAS) that identifies key threats to the reefs and associated reef resources of southeast Florida, and priority actions needed to reduce those threats. SEFCRI is a locally-developed and driven roadmap for collaborative and cooperative action among federal, state, local and non-governmental partners. SEFCRI spans Miami-Dade, Broward, Palm Beach, and Martin Counties, targeting the reefs from the northern border of Biscayne National Park to the St. Lucie Inlet (Figure 5.2). This region was chosen because its highly valued reefs lie close to an intensely developed coastal region with a large and diverse human population. Even though these reefs are exhibiting the same signs of degradation that have been documented in other parts of the world, prior to development of the SEFCRI, there was no coordinated public education or management plan proposed for the reefs located north of Biscayne National Park. Numerous stakeholders were, and continue to be, involved in developing southeast Florida's LAS through a facilitated process including public review and input. The SEFCRI LAS is comprised of 140 projects targeting four focus areas: 1) land-based sources of pollution; 2) fishing, diving, and other uses; 3) awareness and appreciation; and 4) maritime industry and coastal construction impacts (Florida Department of Environmental Protection, 2004). SEFCRI was created in tandem with the development of similar local action strategies in Hawaii, Guam, American Samoa, Commonwealth of the Northern Mariana Islands, U.S. Virgin Islands and Puerto Rico.

In 2004, FDEP established a Coral Reef Conservation Program (CRCP), based in Miami, to complete the development of the LAS, and to plan, direct and coordinate the implementation of SEFCRI. Through the LAS process, the FDEP-CRCP has increased awareness of the extensive and unique resources of, and threats to, the northern extension of the Florida reef tract. The LAS process also provided the framework which has led to improved management and coordination among resource agencies, and expanded the network of stakeholders working on coral reef issues in southeast Florida. Today, in addition to managing and administering SEFCRI, the FDEP-CRCP promotes and coordinates research, monitoring, partnerships, and stakeholder participation for the protection of southeast Florida's reefs, and continues to develop and support the state's efforts through Florida's membership on the U.S. Coral Reef Task Force. In 2006, the FDEP-CRCP also assumed responsibility for coordinating and leading response to vessel groundings and anchor damage incidents in southeast Florida.

### Mapping

Mapping activities in southeast Florida have progressed substantially in the last three years (Figure 5.13). High resolution laser bathymetry has been obtained for the nearshore seafloor (<30 m depth) from Fowey Rocks in South Miami-Dade County to the north Palm Beach County line. In addition to bathymetry, benthic habitats have been mapped for all of Broward and Palm Beach Counties. The benthic habitat mapping efforts employed a multi-technique approach incorporating laser bathymetry, aerial photography, acoustic ground discrimination, video groundtruthing, sub-bottom profiling and expert knowledge (Walker et al., in review). Nova Southeastern University's Oceanographic Center (NSUOC) and the National Coral Reef Institute (NCRI) led this effort with interagency funding by NOAA, the Florida Department of Environmental Protection and the Florida Fish and Wildlife Conservation Commission. The maps were produced by outlining the features in the high resolution bathymetric data and classifying the features based on their geomorphology and benthic fauna. *In situ* data, video camera groundtruthing and acoustic ground discrimination (AGD) were used to help substantiate the classification of the habitats using aerial photography and geomorphology. AGD was also used to further discriminate the sea floor based on the density of organisms. In short, AGD evaluates the shape of sound waves bounced off the seafloor from which different categories of wave shapes are classified. These different wave shapes correspond to different habitats. Many improvements have been made in the acoustic discrimination of coral reef habitats during the southeast Florida mapping, enabling better evaluation of the data. The Broward AGD supplied an additional map layer of relative estimated benthic cover density, whereas the Palm Beach effort has been enhanced to show relative benthic cover density of specific benthic groups- gorgonians and macroalgae. These data supplement the geomorphology-based layer to include not only mapping between features, but also the variability of habitat within features. Accuracy assessment of the map showed high levels of accuracy comparable to that of using aerial photographs in clear water (Walker et al., in review).

The mapping completed thus far supports management of marine resources and scientific research. For example, a GIS evaluation of the nearshore anchorage at Port Everglades has enabled resource managers, commercial interests, enforcement agencies, and scientists to agree on an amendment of the anchorage configuration to help lessen the occurrence of ship groundings and reef impacts by ship anchors. The data are also being used by resource managers to guide decisions on many other proposed construction activities and their associated environmental impacts in the area as well. Future goals for mapping in the area include the continuation of these efforts to the south into Miami-Dade County (gray area in figure) and to the north into Martin County (hatched area in Figure 5.13)

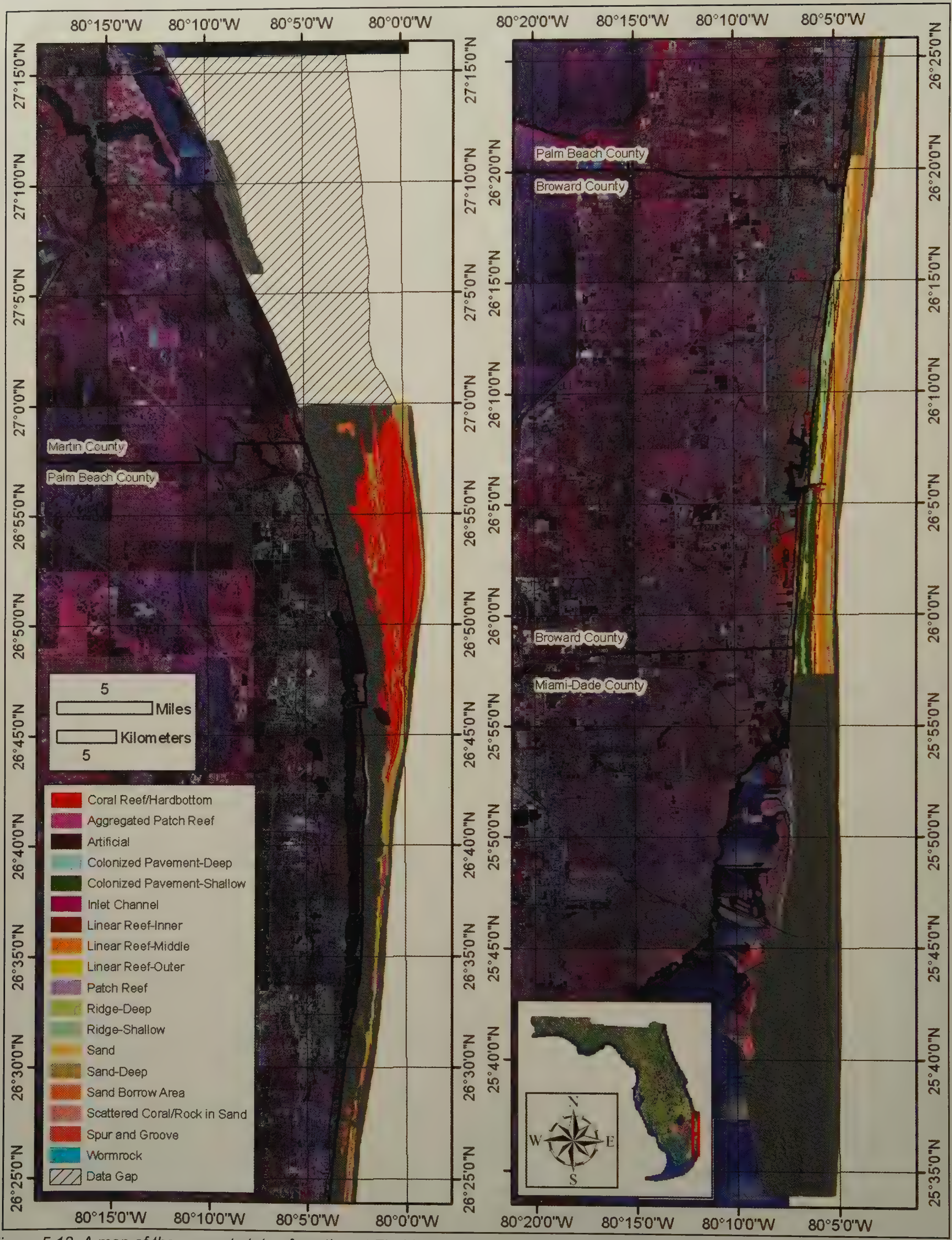

80°15'0"W
80°10'0"W
80°5'0"W
80°0'0"W
80°20'0"W
27°15'0"N
27°10'0"N
27°5'0"N
27°0'0"N
26°55'0"N
26°50'0"N
26°45'0"N
26°40'0"N
26°35'0"N
26°30'0"N
26°25'0"N
26°25'0"N
26°20'0"N
26°15'0"N
26°10'0"N
26°5'0"N
26°0'0"N
25°55'0"N
25°50'0"N
25°45'0"N
25°40'0"N
25°35'0"N
Martin County
Palm Beach County
Palm Beach County
Broward County
Broward County
Miami-Dade County
5
Miles
Kilometers
5
Coral Reef/Hardbottom
Aggregated Patch Reef
Artificial
Colonized Pavement-Deep
Colonized Pavement-Shallow
Inlet Channel
Linear Reef-Inner
Linear Reef-Middle
Linear Reef-Outer
Patch Reef
Ridge-Deep
Ridge-Shallow
Sand
Sand-Deep
Sand Borrow Area
Scattered Coral/Rock in Sand
Spur and Groove
Wormrock
Data Gap
N
W
E
S

*Figure 5.13. A map of the present state of southeast Florida nearshore (<30m depth), seafloor and benthic habitat mapping activities. Benthic habitats have been characterized from southern Martin County to northern Miami-Dade. High resolution bathymetry has been completed from southern Martin County to southern Miami-Dade and a nearshore strip in central Martin County (gray areas). Data gaps are benthic habitats for Miami-Dade County (gray area) and benthic habitats and high resolution bathymetry for Martin County (black hatched area). Image: B. Walker.*

## Monitoring, Assessments and Research

Considerable monitoring and assessment activity is taking place in southeast Florida. The Southeast Florida Coral Reef Evaluation and Monitoring Program (SECREMP) now spans all four counties. The sites provide a needed baseline of information using methods similar to those used for the Florida Keys CREMP program. More sites are needed. The Florida Reef Resilience Program conducts annual surveys for bleaching and disease at sites throughout the four county areas as well. Other monitoring projects conducted by or under the auspices of county and state agencies, academic institutions, or volunteers occur throughout the region. These include temporary (less than five years) benthic organism and reef fish monitoring projects of beach nourishment programs (pre-construction, post-construction). These provide valuable statistical data on status and dynamics of hardbottom communities and reefs. Programs in 2006 included: two in Martin County, seven in Palm Beach County, and one in Broward County. Fish studies in Broward County include assemblage comparison of pre and post nourishment sites and on natural and boulder (mitigation) reefs. Other monitoring efforts include: coral transplants on mitigation artificial reefs in Broward, benthic and fish communities of artificial substrates (limestone boulders and prefabricated artificial reef modules) and of natural reef areas in Broward and Miami-Dade Counties, fish populations of Sabellariid reefs in Palm Beach Counties, fish spawning and algal blooms and *Acropora* spp. in Palm Beach County, benthic and fish communities of artificial and natural reefs in Palm Beach County, and an Annual Fish Count by volunteers in Martin County. There were at least 12 monitoring programs in 2006 (excluding beach renourishment).

Likewise, there are diverse ongoing research projects. Studies in Broward and Miami-Dade Counties involve investigation of efficacy of reef restoration using artificial substrates. In Broward County, benthic recruitment in injury and non-injury areas, coral reproduction and sponge recovery, coral nursery transplantation survival, and *Acropora* spp. expansion are being studied. Since 2004, research has been conducted on recurring benthic cyanobacterial *Lyngbya* spp. blooms on the Broward reefs including seasonality, natural products, and the ecological role of nutrients. Miami-Dade and Broward Counties are or have been involved in investigations into effectiveness and impact of mooring buoys. Palm Beach County studies involve the effectiveness of mitigation reefs, population assessments of hawksbill turtles, and research on gray snapper and snook. Martin studies include evaluating coral condition and water quality impacts using photochemistry

## Marine Protected Areas

Current coral reef management efforts in Florida have primarily focused on the reef tract south of Miami including Biscayne National Park (BNP), the Florida Keys National Marine Sanctuary, John Pennekamp Coral Reef State Park and the Dry Tortugas National Park. No coordinated management plan exists for the 170 km long northern portion of the Florida reef tract extending from BNP to the St. Lucie Inlet in Martin County. Three state parks within the southeast Florida region; John U. Lloyd, John D. MacArthur, and Bill Baggs Cape Florida have boundaries extending 122 m seaward and include hardbottom communities such as limestone, worm rock and coral patch reefs. The 14.5 km$^2$ aquatic portion of the St. Lucie Inlet Preserve State Park (SLIPSP) in Martin County contains extensive coral communities. All state parks in the region afford submerged natural resource protection by prohibiting spearfishing and collecting, although all other recreational and commercial fishing rules apply. Waters within the boundaries of these state parks also received the designation of Outstanding Florida Waters (OFW) which prohibits the pollution of these water masses under Florida Statute 403.061. In 2006, SLIPSP received additional protection through the installation of boundary and mooring buoys. The Broward County Environmental Protection Department maintains 125 mooring buoys on the County's shallow terrace reefs, and a joint effort led by the Florida Fish and Wildlife Conservation Commission, the Wildlife Foundation of Florida, and Palm Beach County Environmental Resource Management was launched in 2006 to establish a mooring ball program for the shallow water reefs in Palm Beach County. Miami-Dade County Department of Environmental Resource Management is also developing a plan to install moorings off the county's reefs.

The Southeast Florida Coral Reef Initiative (SEFCRI) Local Action Strategy, described above, serves as the guidance document for coordinating public education, mitigating threats to southeast Florida reefs and developing recommendations for a management plan for the reefs north of BNP. Several of the local action strategy projects outlined in the Fishing, Diving and Other Uses Focus Areas of SEFCRI will aid the development of an effective strategy to help expand management options beyond OFW and state park efforts.

## Gaps in Monitoring and Conservation Capacity

### *Research, Monitoring and Mapping*

Despite continuing research and progress in implementing benthic habitat monitoring and mapping, many gaps remain in research, mapping and monitoring southeast Florida. Basic management tools such as benthic habitat maps for northern Miami-Dade County, and both bathymetric and benthic habitat maps for Martin County, do not exist. Martin County is the northern limit of shallow water reef building corals along the southeast Florida reef tract and has been given little attention in the past. The only data sets used for mapping in Martin County thus far are limited bathymetry from a NOAA coastal LIDAR survey and coastline aerial photography. Changes in the water flow out of the St. Lucie River from the Everglades restoration project are expected to have a positive impact on the recruitment of reef building corals and reef development in the next several years. Martin County needs to be mapped and monitored for these changes.

A comprehensive, coordinated, long-term regional water quality monitoring program is also essential for reef resource managers to understand the influence of land-based sources of pollution on southeast Florida reefs, and to develop and evaluate effective management to address these threats. The number of SECREMP benthic habitat monitoring sites needs to be increased and linked to water quality monitoring. Reef fish habitat and community monitoring is also needed.

Research priorities include studies to trace nutrients being transported to reef communities from both natural and anthropogenic sources. Research on coral growth, reef succession and recovery rates is needed to establish mitigation protocols for projects impacting reef resources and to ensure appropriate compensation is awarded for lost ecological services resulting from injured coral reef and hardbottom communities. Innovative ways to address the impacts of climate change on coral reefs are also becoming increasingly important.

*Enforcement*
Enforcement efforts related to coral reef and hardbottom habitats in southeast Florida are limited due to the lack of state statutory authority governing damage caused by recreational vessel anchoring and the lack of Special Management Zones prohibiting anchoring over coral reefs. While section 68B-42.009(1) of the Florida Administrative Code addresses the take, destruction, possession and sale of coral, there are no provisions with adequate specificity to restrict recreational anchoring or address unintentional damage to the reefs.

The lack of statutory authority is a problem because it is standard practice throughout all of the coastal counties of Florida, with the exception of Monroe, for recreational vessels to anchor anywhere. Furthermore, in some instances, significant recreational anchoring impacts occur during large-scale marine events that designate vessel spectator areas on the reef tracts. One such annual event is the McDonalds Air and Sea Show that draws close to 3000 anchored boats per day for the two-day event. Other large-scale events include Fourth of July firework shows with offshore presentations. The location of the reefs is not posted, and the current law requires proof that the violator intended to commit damage. The subsequent result is that little enforcement action can be initiated. Due to a shortage of time and resources, inadequate training, and enforcement costs outweighing the potential benefits, officers are unable to make the necessary inspection dives to sufficiently document the damage committed.

Overtaxed manpower also inhibits adequate enforcement. When Florida Fish and Wildlife Conservation Commission (FWC) law enforcement officers are assigned to protect homeland security assets or participate in specialized training programs for homeland security, they are removed from their assigned duties with regard to resource protection. Reduced staff levels due to long-term vacancies further reduce resource protection at all levels. This is of particular concern due to the recent listing of two Acroporid coral species under the Endangered Species Act. Continued shortages in FWC law enforcement will greatly hinder enforcement efforts to protect these threatened species.

*Management*
The SEFCRI LAS has established the need for a comprehensive management plan to conserve, protect and manage the significant coral reef, hardbottom and associated reef resources found along the northern extension of the Florida Reef Tract (FDEP, 2004). However, state and local capacity to develop and implement a new management plan is limited. Increased staff and facilities are needed to support increasing demands on existing programs, as well as to enable and enforce new or expanded efforts. Public and political support for a management plan will also be critical for success and effective action.

## OVERALL CONCLUSIONS AND RECOMMENDATIONS

Since 2004, through the collaborative efforts of local resource managers, scientists and stakeholders, awareness of southeast Florida's reefs, appreciation for their socioeconomic value, and concern for the threats to reef health have markedly increased. New conservation, education and outreach programs and planning have been developed and implemented; and new resource management tools have been created and applied to address local resource management needs and challenges in the region.

However, the unprecedented development of southeast Florida and the multiple pressures from its growing urban population continue to outpace environmental protection efforts at federal, state, local and citizen levels. The loss of coral reef and hardbottom habitats and communities associated with planned public projects continues and the occurrence of coral bleaching and disease is rising. Additionally, pressure on reef resources from recreational and commercial users in southeast Florida is persistent, and the ecological consequences of extractive and non-extractive user activities are serious, and in some cases severe. The urgency of this situation requires a serious increase in effort and support at all levels.

Continued support, adequate funding and increased capacity are critical for ongoing implementation and completion of LAS projects identified in the SEFCRI. High priority LAS projects which remain unfunded require immediate action. These include establishing and maintaining a long-term water quality monitoring program linked to an expanded benthic habitat/community monitoring program, mapping the benthic resources of Martin and Miami-Dade Counties, and conducting research that definitively links land-based sources of pollution to coral reef degradation and quantifies the relative contributions pollution sources.

## Florida Reef Resilience Program

The Florida Reef Resilience Program (FRRP) is a multiyear effort to develop management approaches and tools to better cope with climate change impacts and other stresses on south Florida's coral reefs. The program started in 2004 after creation of a Memorandum of Agreement to facilitate sharing knowledge and best practices for resilience-based management among the state of Florida, NOAA and Australia's Great Barrier Reef Marine Park Authority. The Nature Conservancy is coordinating the FRRP in conjunction with these three agencies and a steering committee of reef managers, scientists, reef user-group representatives and other non-governmental organizations.

The FRRP is designed to improve understanding of reef health in the Florida Keys and southeast Florida region and to identify factors that influence the long-term resilience of corals, reefs and the entire marine ecosystem. With this knowledge in hand, coral reef managers and users can work toward resilience-based management strategies that maximize the benefits of healthy reefs while seeking to improve the condition of those that are less healthy. Ultimately the FRRP seeks to improve ecological conditions on Florida's reefs, economic sustainability of reef-dependent commercial enterprises and compatible recreational uses of reef resources.

A focal area of the FRRP has been filling spatial and temporal information gaps for stony coral bleaching and other bio-indicator monitoring data. The first step in this process was characterization of the 400 km long reef tract from Martin County to the Dry Tortugas into 58 distinct zones. This spatial framework was then used to develop a disturbance response monitoring plan, initially focused on coral bleaching. A sampling design and monitoring protocol were developed by members of the FRRP Benthic Working Group. Reef managers and scientists were trained in the sampling methods which were piloted during the peak bleaching months of 2005, 2006 and 2007. The large number of sample sites (>180) combined with the large geographic area necessitated the involvement and coordination of 12 teams and over 70 divers from multiple agencies, universities and non-governmental organizations. Preliminary results from these surveys indicate spatial and temporal patterns in coral bleaching, disease and mortality, and demonstrate that some coral species and reef types may be more vulnerable to disturbance than others (Figure 5.14). To increase the predictability of thermal stress, these results are also being used to help calibrate remotely-sensed, high resolution (about 1 km) sea surface temperature maps.

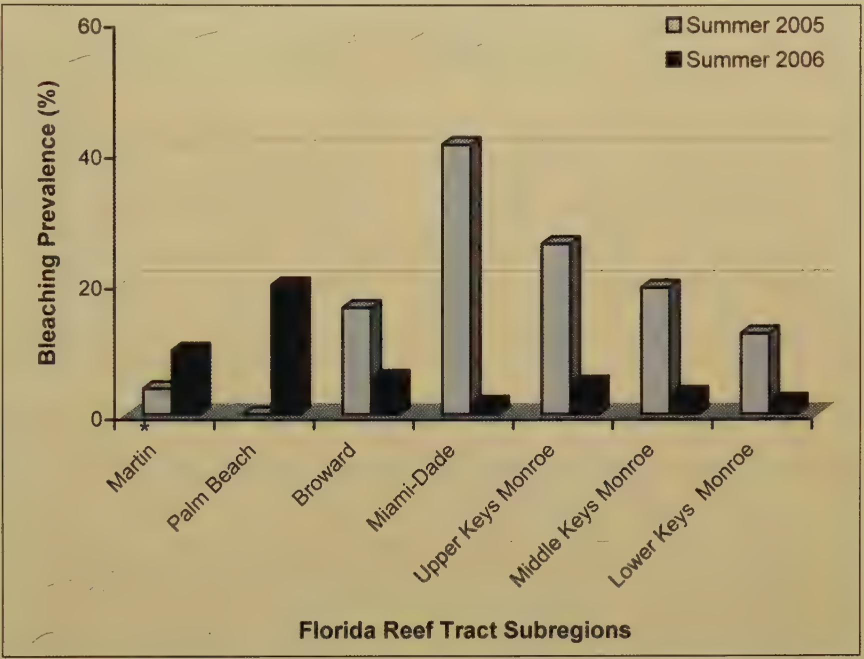


*Figure 5.14. Coral bleaching results from the Florida Reef Resiliency Program surveys completed during the summers of 2005 and 2006. Data for bleaching prevalence is sub-divided into the four counties representing the southeast Florida region and three subregions for Monroe County. Bleaching prevalence is defined as the number of completely and partially bleached corals divided by the total number of corals recorded within each county or subregion. Source: FRRP, unpub. data.*

Another vital aspect of the FRRP is improvement of the information base concerning how people use and value the coral reef ecosystem. Surveys of over 4,000 divers and fishers were conducted in the Florida Keys and the FRRP Human Dimensions Working Group is integrating these results with other socioeconomic and behavioral studies underway in the region. Human dimensions survey results will be related to biophysical study results to provide managers and decision makers with an integrated product to examine different management alternatives.

For more information on the FRRP visit http://www.nature.org/wherewework/northamerica/states/florida/preserves/art17499.html.

Success for many SEFCRI LAS projects is also dependent on the subsequent willingness of the public, industry, and regulatory agencies to adopt the recommendations, guidelines, tools and best management practices developed through SEFCRI and incorporate these conservation strategies into their actions, business practices and programs. However, it is important to recognize that LAS alone are not a complete solution to coral reef conservation and management. A comprehensive management plan, supported by a strengthened outreach and education program and appropriate levels of management capacity, is needed for the reefs of southeast Florida. Improved statutory authority and increased manpower are needed to support and improve coral reef protection and enforcement capacity. New, innovative and compatible, regional, national and international strategies and regulations must also be developed and implemented to address the impacts associated with land-based sources of pollution, climate change and destruction of coral reef resources associated with coastal development and globalization.

Residents, business leaders, visitors, elected officials, scientists and resource managers alike must acknowledge the real threats to both global and local human communities that are associated with the loss of coral reef communities, and be willing to work together to create, support and act on solutions that effectively protect these limited natural resources. As mandated by Presidential Executive Order 13089 (Clinton, 1998), federal agencies whose actions may affect U.S. coral reef ecosystems must: 1) identify such actions; 2) utilize their programs and authorities to protect and enhance the conditions of such ecosystems; and most importantly 3) to the extent permitted by law, ensure that any actions they authorize, fund, or carry out will not degrade the conditions of such ecosystems. State and local government leaders and agencies must act in kind. Stewardship for coral reef resources in Florida, and across the globe, is a responsibility that must be shared.

## REFERENCES

Andrews, K., L. Nall, C. Jeffrey, and S. Pittman. 2005. The State of Coral Reef Ecosystems of Florida. pp. 150-200. In: J.E. Waddell (ed.). The State of Coral Reef Ecosystems of the United States and Pacific Freely Associated States: 2005. NOAA Technical Memorandum NOS NCCOS 11. Silver Spring, MD. 522 pp.

Arena, P.T., L.K.B. Jordan, R.L. Sherman, F.M. Harttung, and R.E. Spieler. 2002. Presence of Juvenile Blackfin Snapper, *Lutjanus buccanella*, and Snowy Grouper, *Epinephelus niveatus*, on Shallow-water Artificial Reefs. pp. 700-712. In: Proceedings of the 55th Gulf and Caribbean Fisheries Institute. Xel Ha, Mexico. 1025 pp.

Arena, P.T., L.K.B. Jordan, and R.E. Spieler. 2007. Fish assemblages on sunken-vessels and natural reefs in southeast Florida, U.S.A. Hydrobiologia 580: 157-151.

Ault, J.S., S.G. Smith, J. Meester, L. Jiangang, and J.A. Bohnsack. 2001. Site characterization for Biscayne National Park: assessment of fisheries resources and habitats. NOAA Technical Memorandum NMFS SEFSC 468. Miami, FL. 185 pp.

Ault, J.S., J.A. Bohnsack, S.G. Smith, and L. Luo. 2005. Towards sustainable multispecies fisheries in the Florida, USA, coral reef ecosystem. Bull. Mar. Sci. 76: 595-622.

Baker, P., J. Fajans, and D. Bergquist. 2003. Invasive Green Mussels, *Perna viridis*, on Mangroves and Oyster Reefs in Florida. p.10. In: Proceedings of the 3rd International Conference on Marine Bioinvasions. La Jolla, California. 136 pp.

Banks, K.W., B.M. Riegl, E.A. Shinn, W.E. Piller, and R.E. Dodge. 2007. Geomorphology of the Southeast Florida continental reef tract (Miami-Dade, Broward, and Palm Beach Counties, USA). Coral Reefs 26: 617-633.

Beal, J. Florida Fish and Wildlife Conservation Commission Habitat and Species Conservation, South Central Florida Marine Habitat Management. Jensen Beach, FL. Personal communication.

Bingham, D. Florida Fish and Wildlife Conservation Commission Law Enforcement. Ft. Lauderdale, FL. Personal communication.

Bohnsack, J.A. and S.P. Bannerot. 1986. A stationary visual census technique for quantitatively assessing community structure of coral reef fishes. NOAA Technical Report NMFS 41. Seattle, WA. 15 pp.

Bohnsack, J.A. and J.S. Ault. 1996. Management strategies to conserve marine biodiversity. Oceanography 9: 73-82.

Bortone, S.A., J.J. Kimmel, and C.M. Bundrick. 1989. A comparison of three methods for visually assessing reef fish communities: time and area compensated. Northeast Gulf Sci. 10: 85-96.

Bryan, D.R. 2006. Reef fish communities on natural substrate and vessel-reefs along the continental shelf of southeastern Florida between 50 and 120m depth. M.S. Thesis. Nova Southeastern University. Fort Lauderdale, FL.

Buddemeier, R.W. and S.V. Smith. 1998. Coral reef growth in an era of rapidly rising sea level: predictions and suggestions for long term research. Coral Reefs 7: 51-56.

Chiappone, M., H. Dienes, D.W. Swanson, and S.L. Miller. 2005. Impacts of lost fishing gear on coral reef sessile invertebrates in the Florida Keys National Marine Sanctuary. Biol. Conserv. 121: 221-230.

Clinton, W.J. 1998. Executive Order 13089: Coral Reef Protection. The White House.

Coastal Planning & Engineering Inc. 2007. Ocean Ridge Shore Protection Project Post-Nourishment Biological Monitoring Report for Palm Beach County Department of Environmental Resources Management. 26 pp.

Coleman, F., G. Dennis, W.C. Jaap, G.P. Schmahl, C. Koenig, S. Reed, and C. Beaver. 2003. Habitat Characterization of Pulley Ridge and the Florida Middle Grounds, Part I: Status and Trends in Habitat Characterization of the Florida Middle Grounds. Coral Reef Conservation Grant Program. Gulf of Mexico Fisheries Management Council. Tampa, FL.

Collier, C., R. Dodge, D. Gilliam, K. Gracie, L. Gregg, W. Jaap, M. Mastry, and N. Poulos. 2007. Rapid Response and Restoration for Coral Reef Injuries in Southeast Florida: Guidelines and Recommendations. 63 pp. http://www.dep.state.fl.us/coastal/programs/coral/reports/MICCI/MICCI_Project2_Guidelines.pdf.

Continental Shelf Associates Inc. 1983. Environmental characterization and impact assessment of the proposed South Lake Worth sand source site. Draft Report. 53 pp.

Continental Shelf Associates Inc. 1985. Ecological assessment of the nearshore rock outcrops off Jupiter Island. Final Report. 33 pp.

Continental Shelf Associates Inc. 2006. Nearshore Artificial Reef Monitoring Report Final Report for Palm Beach County Department of Environmental Resources Management. 44 pp.

Cooke, C.W. and S. Mossom. 1929. Geology of Florida. pp. 29-227 In: Florida Geological Survey 20th Annual Report. 294 pp.

Craig, N. Broward County Environmental Protection Department. Broward County, FL. Personal communication.

Culter, J.K., K.B. Ritchie, S.A. Earle, D.E. Guggenheim, R.B. Halley, K.T. Ciembronowicz, A.C. Hine, B.D. Jarret, S.D. Locker, and W.C. Jaap. 2006. Florida Shelf, U.S.A. Coral Reefs 25: 228.

Dodge, R.E. and K.P. Helmle. 2003. Past stony coral growth (extension) rates on reefs of Broward County, Florida: possible relationships with Everglades drainage. Poster Presentation. Joint Conference on the Science and Restoration of the Greater Everglades and Florida Bay Ecosystem. Palm Harbor, FL.

Edwards, A.J. 1995. Impact of climatic change on coral reefs, mangroves, and tropical seagrass ecosystems. pp. 209-234. In: D. Eisma (ed.). Climate Change: Impact on Coastal Habitation. Lewis Publishers. Boca Raton, FL. 304 pp.

Fauth, J.E., P. Dustin, E. Ponte, K. Banks, B. Vargas-Angel, and C.A. Downs. 2006. Southeast Florida Coral Biomarker Local Action Study. Final Report Southeast Florida Coral Reef Initiative. 69 pp.

Ferro, F.M., L.K.B. Jordan, and R.M. Spieler. 2005. The Marine Fishes of Broward County, Florida: Final Report of 1998-2002 Survey Results. NOAA Technical Memorandum NMFS SEFSC 532. Miami, FL. 73 pp.

Florida Department of Environmental Protection. 2004. Southeast Florida Coral Reef Initiative: A Local Action Strategy. Office of Coastal and Aquatic Managed Areas, Florida Department of Environmental Protection. Miami, FL. 19 pp. http://www.coralreef.gov/las/.

Florida Department of Environmental Protection. 2006. Integrated Water Quality Assessment for Florida: 2006 305(b) Report and 303(d) List Update. Bureau of Watershed Management, Division of Water Resources Management, Florida Department of Environmental Protection. Tallahassee, FL. 235 pp. http://www.dep.state.fl.us/water/tmdl/index.htm.

Gilliam, D.S. 2006. Southeast Florida Coral Reef Evaluation and Monitoring Project 2005 Year 3 Final Report. Prepared for: Florida Fish and Wildlife Conservation Commission, Fish and Wildlife Research Institute, Florida Department of Environmental Protection. 26 pp. http://www.floridadep.org/coastal/programs/coral/reports/.

Gilliam, D.S. 2007. Southeast Florida Coral Reef Evaluation and Monitoring Project 2006 Year 4 Final Report. Prepared for: Florida Fish and Wildlife Conservation Commission, Fish and Wildlife Research Institute, Florida Department of Environmental Protection. 31 pp. http://www.floridadep.org/coastal/programs/coral/reports/.

Gilliam, D.S., R.E. Dodge, R.E. Spieler, L.K.B. Jordan, and J. Monty. 2006. Marine Biological Monitoring in Broward County, Florida: Year 5 Annual Report. Technical Report 05-01. Prepared for the Broward County Board of County Commissioners. Broward County Biological Resources Division and Environmental Protection Department. 90 pp.

Gilliam, D.S., R.E. Dodge, R.E. Spieler, L.K.B. Jordan, and J. Monty. 2007. Marine Biological Monitoring in Broward County, Florida: Year 6 Annual Report. Technical Report 06-01. Prepared for the Broward County Board of County Commissioners. Broward County Biological Resources Division and Environmental Protection Department. 93 pp.

Gilliam, D.S., R.E. Dodge, R.E. Spieler, L.K.B. Jordan, and J. Walczak. In preparation. Marine Biological Monitoring in Broward County, Florida: Year 7 Annual Report. Technical Report 07-02. Prepared for the Broward County Board of County Commissioners. Broward County Biological Resources Division and Environmental Protection Department.

Goldberg, W.M. 1970. Some aspects of the ecology of the reefs off Palm Beach County, Florida, with emphasis on the Gorgonacea and their bathymetric distribution. Masters Thesis. Florida Atlantic University, FL.

Graham, W.M., D.L. Martin, D.L. Felder, V.L. Asper, and H.M. Perry. 2003. Ecological and economic implications of a tropical jellyfish invader in the Gulf of Mexico. Biol. Invasions 5: 53-69.

Gulf of Mexico and South Atlantic Fishery Management Council. 1982. Fishery Management Plan: Final Environmental Impact Statement for Coral and Coral Reefs. 178 pp.

Halley, R., G.P. Dennis, D. Weaver, and F. Coleman. 2005. Characterization of Pulley Ridge Coral and Fish Fauna. Technical Report to the Gulf of Mexico Fisheries Management Council. Tampa, FL. 72 pp.

Harkanson, B. In preparation. A Review of Fish Assemblages on Artificial Reefs in Palm Beach County. Masters Thesis. Nova Southeastern University, FL.

Herren, L., J. Monty, and M. Stokes. 2007. Marine Debris Location, Identification, and Removal from St. Lucie Inlet Preserve State Park Coral Reef, Florida. Mote Marine Laboratory Protect Our Reefs Grant No. POR-2005B-1. 26 pp.

Hitchcock, G.L., T.N. Lee, P.B. Ortner, W.E. Keble, and E. Williams. 2005. Property Fields in a Tortugas Eddy in the Southern Straits of Florida. Deep Sea Research Part I-Oceanographic Research Papers 52: 2195-2213.

Hopkins, T.S., D.R. Blizzard, S.A. Brawley, S.A. Earle, D.E. Grimm, D.K. Gilbert, P.G. Johnson, E.H. Livingston, C.H. Lutz, J.K. Shaw, and B.B. Shaw. 1977. A Preliminary Characterization of the Biotic Components of Composite Strip Transects on the Florida Middlegrounds, Northeastern Gulf of Mexico. pp. 31-37. In: D.L. Taylor (ed.). Proceedings from 3rd International Coral Reef Symposium, Vol. 1. Miami, FL. 656 pp.

Jarrett, B.D., A.C. Hine, R.B. Halley, D.F. Naar, S.D. Locker, A.C. Neumann, D. Twichell, C. Hu, B.T. Donahue, W.C. Jaap, D. Palandro, and K.T. Ciembronowicz. 2005. Strange bedfellows - a deep-water hermatypic coral reef superimposed on a drowned barrier island: southern Pulley Ridge, SW Florida platform margin. Mar. Geol. 215: 295-307.

Johns, G.M., V.R. Leeworthy, F.W. Bell, and M.A. Bonn. 2001. Socioeconomic Study of Reefs in Southeast Florida. Final Report. Hazen and Sawyer Environmental Engineers & Scientists.

Johns, G.M., J.W. Milon, and D. Sayers. 2004. Socioeconomic Study of Reefs in Martin County, FL. Final Report. Hazen and Sawyer Environmental Engineers & Scientists.

Johnson, D.R., D.E. Harper, G.T. Kellison, and J.A. Bohnsack. 2007. Description and Discussion of Southeast Florida Fishery Landings, 1990-2000. NOAA Technical Memorandum NMFS SEFSC 550. Miami, FL. 64 pp.

Lapointe, B.E. 1997. Nutrient thresholds for bottom-up control of macroalgal blooms on coral reefs in Jamaica and southeast Florida. Limnol. Oceanogr. 42: 1119-1131.

Lapointe, B.E, P.J. Barile, M.M. Littler, D.S. Littler, B.J. Bedford, and C. Gasque. 2005a. Macroalgal blooms on southeast Florida coral reefs: I. Nutrient stoichiometry of the invasive green alga *Codium isthmocladum* in the wider Caribbean indicates nutrient enrichment. Harmful Algae 4: 1092-1105.

Lapointe, B.E., P.J. Barile, M.M. Littler, and D.S. Littler. 2005b. Macroalgal blooms on southeast Florida coral reefs: II. Cross-shelf d15N values provide evidence of widespread sewage enrichment. Harmful Algae 4: 1106-1122.

Lapointe, B.E., B.J. Bedford, and R. Baumberger. 2006. Hurricanes Frances and Jeanne Remove blooms of the invasive green alga *Caulerpa brachypus forma parvifolia* (Harvey) Cribb from coral reefs off northern Palm Beach County, FL. Est. Coast. 29: 966-971.

Leichter, J.J., H.L. Stewart, and S.L. Miller. 2003. Episodic nutrient transport to Florida coral reefs. Limnol. Oceanogr. 48: 1394-1407.

Lighty, R.G. 1977. Relict shelf-edge Holocene coral reef: southeast coast of Florida. pp. 215-221. In: D.L. Taylor (ed.). Proceedings from the 3rd International Coral Reef Symposium, Vol 2. Miami, FL. 628 pp.

Mace, P. 1997. Developing and sustaining world fishery resources: state of science and management. pp. 1-20. In: D.A. Hancock, D.C. Smith, A. Grant, and J.P. Beurner (eds.). Proceedings of the Second World Fishery Congress. Brisbane, Australia. 797 pp.

McArthur, C.J., S.J. Stamates, and J.R. Proni. .2006. Review of the Real-Time Current Monitoring Requirement for the Miami Ocean Dredged Material Disposal Site. NOAA Technical Memorandum OAR AOML 95. Miami, FL. 13 pp.

McDevitt, E. Southeast Florida Marine Habitat Management, Division of Habitat and Species Conservation, Florida Fish and Wildlife Conservation Commission. West Palm Beach, FL. Personal communication.

National Marine Fisheries Service (NMFS). 2005. 2005 Report of Status of U.S. Fisheries. 20 pp. http://www.nmfs.noaa.gov/sfa/statusoffisheries/SOSmain.htm.

NOAA AOML Keynotes. 2006. FACE Program Begins Sampling Efforts Along Florida Coast. AOML Keynotes 10(5): 1-2.

The Ocean Conservancy. 2005. 2005 International Coastal Cleanup Summary Report: Florida. 7 pp. http://www.oceanconservancy.org/site/News2?page=NewsArticle&id=8635.

The Ocean Conservancy. 2006. 2006 International Coastal Cleanup Summary Report: Florida. 9 pp. http://www.oceanconservancy.org/site/News2?page=NewsArticle&id=10393.

Palm Beach County Department of Environmental Resources Management. 1993. Environmental assessment of coastal resources in Palm Beach, Lake Worth, South Palm Beach, Lantana and Manalapan. Final Report. Palm Beach County, FL. 144 pp.

Palm Beach County Department of Environmental Resources Management. 1994. Environmental assessment for a shore protection project at Ocean Ridge. Final Report. Palm Beach County, FL. 58 pp.

Palm Beach County Reef Research Team. 2004. Final Report for 4 November, 2002 to 1 December 2004 Grant Period. Unpublished report. 393 pp.

Paul, V.J., R.W. Thacker, K. Banks, and S. Golubic. 2005. Benthic cyanobacterial bloom impacts the reefs of South Florida (Broward County, USA). Coral Reefs 24: 693-697.

PBS&J. 1999. Assessment of stony coral impacts along telecommunication cables in Broward County, Florida. A report for Michael S. Tammaro, Carlton, Fields, Ward, Emmanuael, Smith & Culter, PA.

Perry, H.M., T. Van Devender, W. Graham, D. Johnson, K. Larsen, W.D. Burke, and C. Trigg. 2000. Diaphanous denizens from down under: first occurrence of *Phyllorhiza punctata* in Mississippi coastal waters. Gulf and Caribbean Fisheries Institute Annual Meeting. Biloxi, MS.

Phipps, J. Palm Beach County Department of Environmental Resources Management. West Palm Beach, FL. Personal communication.

Pielke, R.A., R.L. Walko, L.T. Steyaert, P.R. Vidale, G.E. Liston, W.A. Lyons, and T.N. Chase. 1999. The influence of anthropogenic landscape changes on weather in south Florida. American Meteorological Society 127: 1663-1672.

Porch, C.E., A.M. Eklund, and G.P. Scott. 2003. An assessment of rebuilding times for goliath grouper. SEDAR6-RW-3. Sustainable Fisheries Division, NMFS Southeast Fisheries Science Center. Miami, FL. 25 pp. http://www.sefsc.noaa.gov/sedar/.

Porch, C.E., A.M. Eklund, and G.P. Scott. 2006. A catch-free stock assessment model with application to goliath grouper (*Epinephelus itajara*) off southern Florida. Fish. Bull. 104: 89-106.

Proni, J. NOAA Atlantic Oceanographic and Meteorological Laboratory (AOML). Miami, FL. Personal communication.

REEF. 2007. Reef Environmental Education Foundation Volunteer Survey Project Database. www.reef.org.

Semmens, B.X., E.R. Buhle, A.K. Salomon, and C.V. Pattengill-Semmens. 2004. A hotspot of non-native marine fishes: evidence for the aquarium trade as an invasion pathway. Mar. Ecol. Prog. Ser. 266: 239-244.

Sherman, R.L., D.S. Gilliam, and R.E. Spieler. 1999. A preliminary examination of depth associated spatial variation in fish assemblages on small artificial reefs. J. Appl. Ichthyol. 15: 116-122.

Sherman, R.L., D.S. Gilliam, and R.E. Spieler. 2001. Artificial reef design: void space, complexity and attractants. ICES J. Mar. Sci. 59: 196-200.

South Florida Water Management District. 1996. Climate Change and Variability: How Should the District Respond? West Palm Beach, FL. 130 pp.

Szmant, A.M. 2002. Nutrient enrichment on coral reefs: is it a major cause of coral reef decline? Estuaries 25: 743-766.

Tichenor, E. 2003. The Occurrence and Distribution of Cyanobacteria on Gulf Stream Reef, Boynton Beach, Florida. Palm Beach County Reef Rescue. Boynton Beach, FL. 27 pp. http://www.reef-rescue.org/PDFreports.shtml.

Tichenor, E. 2004a. The Occurrence and Distribution of Cyanobacteria on Gulf Stream Reef, Boynton Beach, Florida. Result of Phase II Investigations. Palm Beach County Reef Rescue. Boynton Beach, FL. 47 pp. http://www.reef-rescue.org/PDFreports.shtml.

Tichenor, E. 2004b. Correlation between Waste Water Treatment Plant Effluent Quality and Cyanobacteria Proliferation on Gulf Stream Reef System, Boynton Beach, Florida. Palm Beach County Reef Rescue. Boynton Beach, FL. 60 pp. http://www.reef-rescue.org/PDFreports.shtml.

Tichenor, E. 2005. The Occurrence and Distribution of Cyanobacteria on Gulf Stream Reef, Boynton Beach, Florida. Palm Beach County Reef Rescue. Boynton Beach, FL. 82 pp. http://www.reef-rescue.org/PDFreports.shtml.

Trimble, P.J., E.R. Santee, and C.J. Neidrauer. 2006. Preliminary Estimate of Impacts of Sea Level Rise on the Regional Water Resources of Southeastern Florida. Hydrologic Systems Modeling Division, South Florida Water Management District. 10 pp.

Trnka, M., K. Logan, and P. Krauss. 2006. Land-Based Sources of Pollution-Local Action Strategy Combined Projects 1 and 2. Report prepared for the Southeast Florida Coral Reef Initiative. Miami, FL. 200 pp.

U.S. Census Bureau. 2006. Cumulative Estimates of Population Change for the United States, Regions, States and Puerto Rico and Region and State Rankings: April 1, 2000 to July 1, 2006. http://www.census.gov/popest/states/NST-pop-chg2006.html.

U.S. Census Bureau. 2007a. http://www.census.gov/

U.S. Census Bureau. 2007b. Cumulative Estimates of Population Change for Counties of Florida and County Rankings: April 1, 2000 to July 1, 2003. http://www.census.gov/popest/counties/tables/CO-EST2003-02-12.pdf.

U.S. Coral Reef Task Force. 2000. The National Action Plan to Conserve Coral Reefs. Washington, DC. 34 pp.

U.S. Fish and Wildlife Service- Southeast Region. 2004. Investigations of mitigation for coral reef impacts in the U.S. Atlantic: South Florida and the Caribbean. Final report. 97 pp.

University of Florida. 2006. Florida Statistical Sources. http://www.uflib.ufl.edu/fefdl/florida/fl_statistics.html.

Vare, C.N. 1991. A survey, analysis, and evaluation of the nearshore reefs situated off Palm Beach County, Florida. Masters Thesis. Florida Atlantic University, FL.

Vargas-Angel, B., J.D. Thomas, and S.M. Hoke. 2003. High-latitude *Acropora cervicornis* thickets of Ft. Lauderdale, Florida, USA. Coral Reefs 22: 465-473.

Vince, G. South Florida Water Management District. West Palm Beach, FL. Personal communication.

Walker, B.K., B. Riegl, and R.E. Dodge. In review. Mapping Coral Reef Habitats: A Combined Technique Approach. J. Coast. Res.

Wanless, H.R. 1989. The inundation of our coastlines: past, present, and future with a focus on south Florida. Sea Front. 35: 264-271.

Whitfield, P., T. Gardner, S.P. Vives, M.R. Gilligan, W.R. Courtenay Jr., G.C. Ray, and J.A. Hare. 2002. Biological invasion of the Indo-Pacific lionfish (*Pterois volitans*) along the Atlantic coast of North America. Mar. Ecol. Prog. Ser. 235: 289–297.

Whitfield, P.E., A.H. Jonathan, A.W. David, S.L. Harter, R.C. Munoz, and C.M. Addison. 2007. Abundance estimates of the Indo-Pacific lionfish *Pterois volitans/miles* complex in the Western North Atlantic. Biol. Invasions 9: 1387-3547.

Wilkinson, C.R. 1996. Global change and coral reefs: Impacts on reefs, economies and human cultures. Global Change Biol. 2: 547-558.

# The State of Coral Reef Ecosystems of the Florida Keys

Scott Donahue[1], Alejandro Acosta[2], Lad Akins[3], Jerald Ault[4], James Bohnsack[5], Joseph Boyer[6], Michael Callahan[2], Billy Causey[1,9], Carrollyn Cox[2], Joanne Delaney[1], Gabriel Delgado[2], Kent Edwards[1,7], George Garrett[8], Brian Keller[9], G. Todd Kellison[5], V. Robert Leeworthy[10], Lauri MacLaughlin[1], Loren McClenachan[11], Margaret W. Miller[5], Steven L. Miller[12], Kim Ritchie[13], Steven Rohmann[10], Deborah Santavy[14], Christy Pattengill-Semmens[3], Benjamin Sniffen[1], Stephen Werndli[1] and Dana E. Williams[5]

## INTRODUCTION AND SETTING

In this chapter, the authors present the latest in a series of updates to this living document. The 2005 edition of this report provided a good basis for this update, as it nicely detailed the coral reefs of the Florida Keys and southeast Florida, along with their associated oceanography, reef geomorphology and geology, and socioeconomic importance (Andrews et al., 2005). This edition of the report provides two separate chapters for the coral reefs of Florida in appreciation of their separate regulatory histories and the different reef types present in the Florida Keys and the Southeast region. The two chapters will complement each other and should be used to highlight the challenges associated with managing a coral reef ecosystem that extends over 480 km (300 miles). Contributing authors for the Florida chapter in Waddell (2005) were contacted for this chapter and only those updates available at the time of this writing were included. Manuscripts and information that were in preparation will be included in the next edition of this volume. Figure 6.1 highlights locations mentioned throughout this chapter.

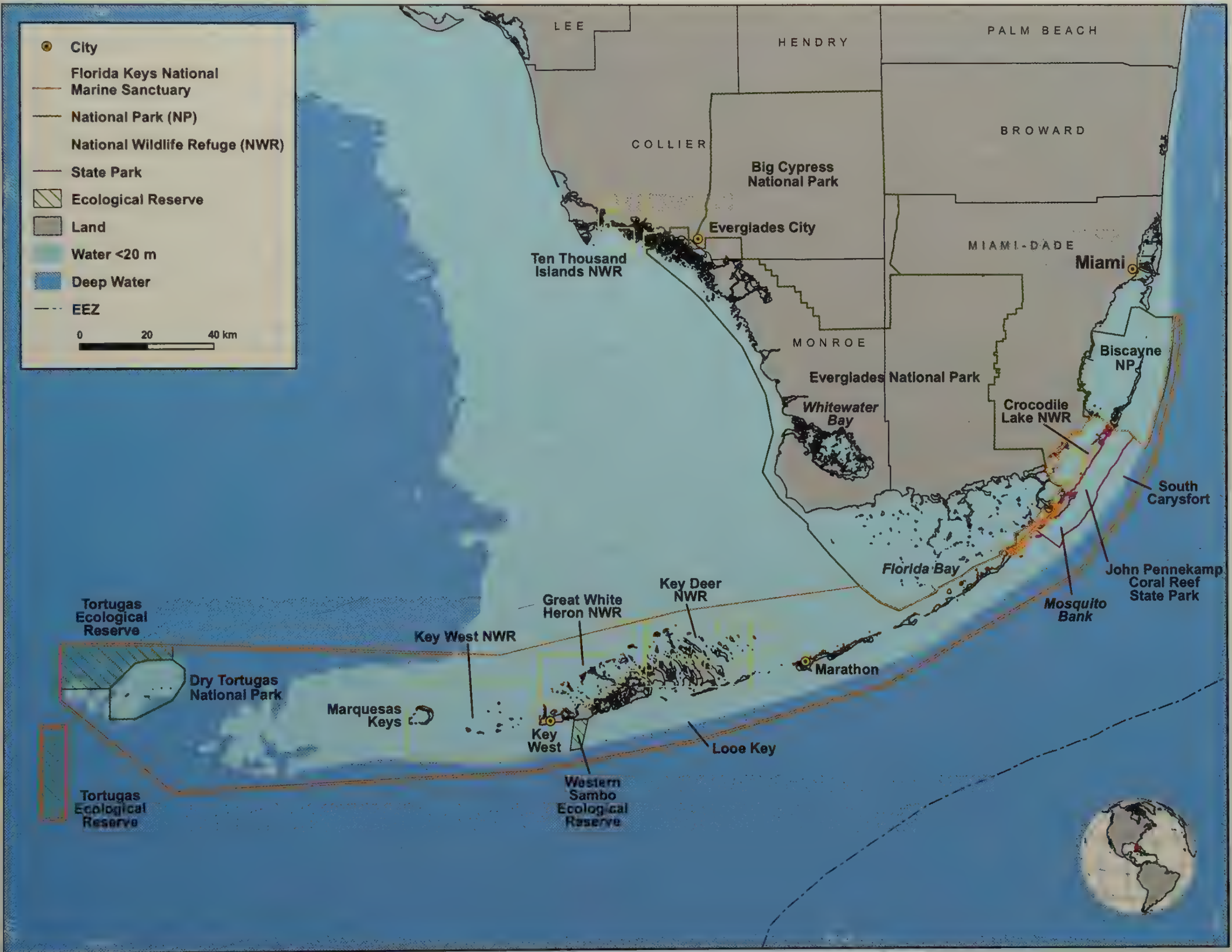

City
Florida Keys National Marine Sanctuary
National Park (NP)
National Wildlife Refuge (NWR)
State Park
Ecological Reserve
Land
Water <20 m
Deep Water
EEZ
0
20
40 km
LEE
HENDRY
PALM BEACH
COLLIER
BROWARD
Big Cypress National Park
Everglades City
MIAMI-DADE
Miami
Ten Thousand Islands NWR
MONROE
Biscayne NP
Everglades National Park
Whitewater Bay
Crocodile Lake NWR
South Carysfort
Florida Bay
John Pennekamp Coral Reef State Park
Mosquito Bank
Key Deer NWR
Great White Heron NWR
Tortugas Ecological Reserve
Key West NWR
Marathon
Dry Tortugas National Park
Marquesas Keys
Key West
Looe Key
Western Sambo Ecological Reserve
Tortugas Ecological Reserve

Figure 6.1. Locator map of the Florida Keys depicting locations mentioned in this chapter. Map: K. Buja.

---

1. NOAA, Florida Keys National Marine Sanctuary
2. Florida Fish and Wildlife Conservation Commission, Fish and Wildlife Research Institute
3. Reef Environmental Education Foundation
4. University of Miami, Rosenstiel School for Marine and Atmospheric Science
5. NOAA, Southeast Fisheries Science Center
6. Florida International University, Southeast Environmental Research Center
7. Florida Department of Environmental Protection
8. Monroe County Division of Marine Resources
9. NOAA, Office of National Marine Sanctuaries
10. NOAA, National Ocean Service, Special Projects Office
11. Scripps Institute of Oceanography
12. University of North Carolina, Wilmington
13. Mote Marine Laboratory
14. U.S. Environmental Protection Agency, Gulf Ecology Division9.

## ENVIRONMENTAL AND ANTHROPOGENIC STRESSORS

### Climate Change and Coral Bleaching

Although elevated sea surface temperatures (>31°C) returned to the Florida Keys in 2004 and 2005, only minor to moderate coral bleaching was observed in patchy patterns on the coral reefs. While severe coral bleaching events were observed and recorded in other parts of the U.S. Caribbean, the Florida Keys escaped most of the stressful environmental conditions experienced elsewhere. Due to an active hurricane season both in 2004 and 2005, extended periods of doldrum-like weather patterns did not establish in the Florida Keys. The passage of each tropical storm or hurricane decreased sea surface temperatures, as well as allowing for mixing of the surface waters due to intense winds.

Figure 6.2 shows how the waters cooled off just after the passage of three hurricanes in the Florida Keys in 2005. Illustrated are the 2004 and 2005 sea surface temperatures that were recorded at a SeaKeys C-Man station established at Sombrero Reef located on the reef tract off the middle Florida Keys. In 2005, elevated sea surface temperatures (>31°C) were present between July and September 2005. Doldrum-like weather patterns persisted for most of the time and corals began to bleach and show signs of stress. Before a mass bleaching event occurred, the passage of Hurricanes Katrina, Rita and Wilma alleviated the stressful conditions of elevated sea surface temperatures and doldrum weather patterns. More information on the effects of bleaching on reefs in the Florida Keys can be found in the Benthic Habitats section of this chapter.

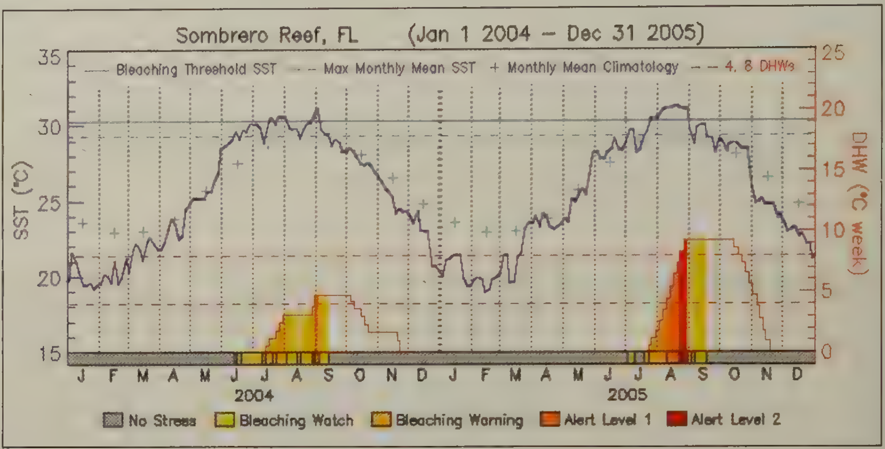


*Figure 6.2. Sea surface temperatures (SST) recorded at Sombrero Reef in the Florida Keys between January 2004 and December 2005. Passage of hurricanes Katrina, Rita and Wilma in September and October 2005 alleviated the stressful conditions of elevated sea surface temperatures and doldrum weather patterns. DHW=Degree Heating Weeks. Source: NOAA/ NESDIS.*

### Diseases

Corals throughout the Caribbean and Atlantic region have suffered from numerous diseases over the past several decades, and disease has been implicated in the demise of a number of reef building species. Two studies in the Florida Keys track disease prevalence at monitoring stations throughout the archipelago. In one study, the prevalence of diseases has been shown to vacillate over time, and since 2002 has generally decreased at monitored stations within Florida Keys National Marine Sanctuary (FKNMS) and at the Dry Tortugas. Because diseases can be difficult to distinguish in the field, this study grouped white diseases (white plague, white pox, white band) to differentiate them from black band disease, while the remainder of disease states fell into an "Other" category. The number of stations affected with white diseases peaked to more than 80% in 2002, subsided to 35% in 2005, then increased again to 50% in 2006. The number of stations affected with Other diseases peaked to 90% in 2001, but declined to 57% by 2006. The other reported study, which was conducted in August of 2006, focused on diseases affecting two species of coral that had been recently listed as threatened on the U.S. Endangered Species List: *Acropora cervicornis* and *A. palmata*. The group surveyed 107 sites along about 46 km of coastline in the upper keys and fortunately found no evidence of white band or other diseases affecting either species. More information on the effects of coral diseases on reefs in the Florida Keys can be found in the Benthic Habitats section of this chapter.

### Tropical Storms

Tropical cyclones are an annual threat to Florida coastal ecosystems and may impose a variety of devastating effects, including storm surge, freshwater flooding due to excessive rainfall and damaging winds. The 2005 hurricane season had very serious impacts to Florida coastal resources, whereas the 2006 and 2007 seasons produced more minor, localized impacts (Figure 6.3). The record-breaking 2005 Atlantic Hurricane Season produced a total of 28 named tropical storms, 15 of which attained hurricane strength throughout the Atlantic, Caribbean Sea and Gulf of Mexico. Of these storms, five tropical cyclones directly impacted the Florida Keys, with a frequency of one storm per month. Tropical Cyclone Arlene, the first one to affect Florida Keys in 2005, passed west of Dry Tortugas before making landfall west of Pensacola in early June. Hurricane Dennis passed over Dry Tortugas approximately one month later, causing severe erosion from west of John Pennekamp State Park through the Dry Tortugas. Compared with the other tropical cyclones to affect the Florida Keys in 2004 and 2005, Dennis was noted by FKNMS resource managers for its powerful hydrodynamic energy. Approximately a month and a half later, Hurricane Katrina struck south Florida as a Category 1 hurricane in late August. Only minor wind and storm surge damage was reported throughout mainland south Florida, however, rainfall in excess of 10 inches produced major freshwater flooding southwest of Miami and throughout the Lower Florida Keys. As Katrina passed over the Dry Tortugas, only minor overwash of the sand beaches and docks was reported. Hurricane Rita passed south of the Florida Keys in late September. While minor wind damage and no freshwater flooding was reported, significant storm surge flooding in excess of 5 ft above normal was reported along Atlantic-facing shores of the Keys, producing widespread overwash of sand beaches. The last tropical cyclone to affect Florida in 2005 was Hurricane Wilma, which was the most devastating to the Florida Keys. Wilma struck the coastline of extreme southwest Florida, south of Everglades City, in late October as a major hurricane. Widespread storm surge reached 8 ft above normal and completely overwashed most of Florida Keys from Marathon westward, with storm surge likely in excess of 8 ft across the Everglades coastline south of Everglades City. Severe wind damage was also noted in the Key West National Wildlife Refuge in the Marquesas Keys, with numerous mangrove branches snapped and some plants completely uprooted. While damage to mangrove forests resulted in some displacement of local bird populations, sand deposition on beaches may have benefited turtles nesting in the Keys. The 2006 hurricane season included two landfalls in Florida: Tropical Storm Alberto along the Big Bend coastline in June, and Hurricane Ernesto (which soon weakened to tropical storm intensity) which swept across the Florida Keys and southwest Florida in August. Ernesto did not produce significant coastal erosion in the Florida Keys.

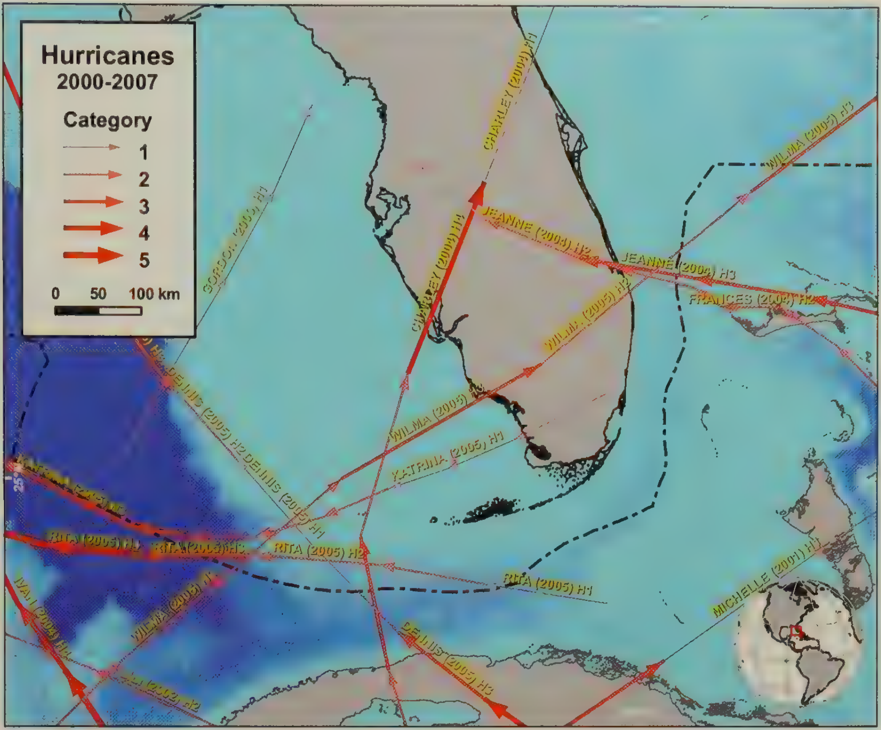


Figure 6.3. The paths and intensities of tropical storms affecting the Florida Keys, 2000-2007. Storm name, year and strength are indicated for each. Map: K. Buja. Source: http://maps.csc.noaa.gov/hurricanes/.

Damage and destruction resulting from tropical cyclones are usually thought of in terms of land-based observations. However, the marine ecosystem is always affected by these storms as well. Many marine habitats surveyed in the Dry Tortugas region suffered obvious physical damage (e.g., overturned coral colonies) and scouring from the storms that hit the region in 2005. Many areas that were gorgonian-dominated hard-bottom habitats in 1999-2000 and 2002, especially in the southern portion of Dry Tortugas National Park (DTNP), are now devoid of most gorgonians and sponges. Interestingly, concurrent reef fish surveys documented a marked decline in the abundance of juveniles of some species (e.g., black grouper) that were previously relatively abundant in these habitats. Reef terraces on Little Tortugas Bank and the northwestern Tortugas Bank (Sherwood Forest) are still in relatively good condition in terms of coral abundance, but coral cover has apparently declined from about 50% to about 35% in some areas. In these same sites, scientists noticed an increased prevalence of the brown alga *Lobophora variegata* that now occupies space once covered by live coral. A few sites also exhibited relatively high prevalence of coral disease, especially by what is believed to be white plague. At one site in particular, approximately 25% of the corals were afflicted with this condition. The factors responsible for increasing disease prevalence are unknown. The hypothesis that coral bleaching and other stressors increase susceptibility to disease needs to be tested. However, the extent, severity and degree of recovery from coral bleaching that occurred in 2005 are unknown.

Relative to 1999-2000, June 2006 sampling efforts revealed that sea urchins, especially *Diadema antillarum*, were more abundant and were found in relatively dense aggregations (>0.3 individuals/m$^2$) in some of the shallow water patch reef, hardbottom and medium-profile reef areas in DTNP (Miller et al., 2006a). While *Diadema* densities are still below the estimated historical (pre-1983) densities (approximately 1 individual/m$^2$ for certain habitat types), urchin densities in the Tortugas region, especially within DTNP, remain about an order of magnitude higher than levels documented in the rest of the Florida Keys. An increase in the number of recently recruited juvenile *Diadema* in the region is encouraging; peak recruitment in south Florida normally occurs during August and September. Of the 98 *Diadema* recorded at 46 monitoring sites, about 75% measured less than 1 cm in test diameter and were believed to have settled in the previous two months.

## Coastal Development and Runoff

A major influence on water quality in Florida Bay and the Keys is runoff from south Florida and the Everglades. In the later third of the 20th century, it was recognized that modifications to drainage of fresh water in the south Florida region resulted in serious environmental effects. The drainage system, known as the Central and Southern Florida Project (C&SF), was constructed by the U.S. Army Corps of Engineers (USACE) and was the focal point of the south Florida water management system for the past 50 years. The Water Resource Development Acts of 1992 and 1996 provided the USACE with the authority to review the C&SF, and to develop a comprehensive plan to restore and preserve the south Florida ecosystem by enhancing fresh water flow into the Everglades while maintaining flood protection in the surrounding areas. In April 1999, the Comprehensive Everglades Restoration Plan (CERP) was finalized, which detailed more than 60 major changes to fresh water delivery that needed to occur in and around the Florida Everglades. If implemented, these changes will affect an area of more than 18,000 square miles. More information on CERP can be found at http://www.evergladesplan.org/index.aspx.

Coastal development also affects nearshore water quality in the Florida Keys, and as a result, Monroe County has developed Master Stormwater and Wastewater Plans (MSWWW) designed to comprehensively address the significant local sources of pollution in Florida Keys waters. Construction has been completed on some of the MSWWW projects and several others have been initiated. Additionally, the state of Florida has mandated that all homes and businesses in Monroe county be hooked up to centralized sewage treatment plants (the wastewater portion of the MSWWW) by the year 2010, thus the county government is actively seeking funding from several sources to meet this aggressive schedule. There are also several local, state and federal regulatory programs in place that were designed to reduce and mitigate the impacts of upland development on natural habitats and coastal water quality. More information about these programs can be found on the Internet for Monroe County (Rate of Growth Ordinance, Section 9.5-120 Monroe County Code http://www.municode.com/resources/gateway.asp?sid=9&pid=11270) and state and federal wetlands and surface water (http://www.dep.state.fl.us/water/wetlands/erp/index.htm).

In an effort to keep the beach-going public informed about water-borne microorganisms that could cause disease, infections or rashes, the Florida Department of Health monitors water quality at a number of beaches in 34 coastal counties. Monroe County has 17 beaches that are tested weekly for *Enterococci* and fecal coliform bacteria. High concentrations of these bacteria prompts the issuance of health advisories or warnings for that week. There were 884 beach weeks tested in Monroe County in 2006 (17 beaches x 52 weeks), ninety of the tests (about 10%) resulted in advisories and warnings. Additional information about beach water quality for the Florida Keys can also be found at http://esetappsdoh.doh.state.fl.us/irm00beachwater/default.aspx?county=Monroe.

### Coastal Pollution

In addition to the information presented in the Costal Development and Runoff section above, please refer to the Southeast Florida chapter of the 2005 edition of this report (Andrews et al., 2005) for further information.

### Tourism and Recreation

Artificial reefs have previously been deployed in the Florida Keys (e.g., at Adolphus Busch, Thunderbolt, Duane, etc.). In 2000-2001, Johns et al. (2001) estimated that both residents and visitors of the Florida Keys spent 1.58 million person-days snorkeling, SCUBA diving and fishing on the artificial reefs in the FKNMS. This activity generated over $131 million in output/sales, $31 million in income, and 2,365 full and part-time jobs in Monroe County. In addition, the artificial reefs had an estimated net annual user value of $9.75 million with an asset value of $57.5 million. Residents and visitors were willing to pay annually an additional $2 million for new artificial reefs.

The FKNMS currently has a moratorium on deployment of additional artificial reefs, with the exception of the USS *Vandenberg*, which was given approval by National Oceanic and Atmospheric Administration (NOAA) and FKNMS in 2003 and is scheduled to be placed in mid-2008. The moratorium was enacted because of concerns about whether artificial reefs will harm or help the natural reefs in the FKNMS.

In June 2002, the retired navy ship USS *Spiegel Grove* was sunk in the waters off Key Largo in the FKNMS. At 510 ft, the *Spiegel Grove* was at the time the largest vessel ever intentionally sunk for the purpose of creating an artificial reef within the FKNMS. Proponents of the *Spiegel Grove* argued that the ship's role as an artificial reef would take pressure off the surrounding natural reefs and thus provide an ecological benefit. Leeworthy et al. (2006) tested this hypothesis over a 10-month period via a pre- and post-sinking monitoring effort. A combination of dive shop logbooks and on-water observation were used to estimate total use on the artificial and natural reefs surrounding the area where the *Spiegel Grove* was to be sunk. The study found that after the sinking of the *Spiegel Grove*, usage of surrounding natural reefs declined 13.7%, while use of artificial reefs increased 160.5% and total reef use (artificial and natural) increased 9.3%. In addition, dive shop business increased 3.7% and total recreation and tourism increased as well, resulting in an additional $2.7 million in total sales/output, $962,000 in income and 68 full and part-time jobs in the Monroe County economy.

Additional visitor and resident surveys to track the use of Florida Keys reefs and associated economic benefits are scheduled to be conducted in 2008 and summary results and reports are expected to be available according to the schedule in Table 6.1. More detailed analysis of the data, which requires more time to analyze, review and publish, will be included in future versions of this report as it becomes available.

*Table 6.1. Schedule of completion for the Florida Keys Visitor Survey reports. Source: V.R. Leeworthy.*

| AVAILABLE | REPORT |
|---|---|
| April 15, 2009 | Visitor Profiles Report |
| May 15, 2009 | Visitor Economic Contribution Report |
| June 15, 2009 | Visitor Importance - Satisfaction Ratings Report |
| June 15, 2009 | Resident Survey Report: Profiles, Economic Contribution and Importance-Satisfaction Ratings |
| July/August 2009 | Visitor and Resident Survey: Knowledge, Attitudes and Perceptions of Sanctuary Management Strategies and Regulations |

### Knowledge, Attitudes and Perceptions of Regulations and Management Strategies in the FKNMS

In 2005, NOAA funded replication of a baseline study completed in 1995-1996 by researchers at the University of Florida and the University of Miami's Rosenstiel School of Marine and Atmospheric Sciences through a Florida Sea Grant Project. Baseline information was obtained on the knowledge, attitudes and perceptions about regulations and management strategies being proposed for the FKNMS and the no-take areas established in 1997. The baseline and 10-year replication will assess changes in the knowledge, attitudes and perceptions of FKNMS regulations and management strategies for three user groups: commercial fishermen, dive shop owners and operators and members of local environmental groups. Surveys of commercial fishermen and dive shop owners/operators were completed in 2006. A 100% response rate was achieved on a random sample of 300 commercial fishing operations, and a 95% response rate was achieved for all 65 dive shop owners/operators in the Florida Keys in 2006. The survey of members of local environmental groups began in December 2006 and was completed in May 2007. Analyses and reports are expected to be available by 2008. For more information about ongoing socioeconomic research, visit http://marineeconomics.noaa.gov/welcome.html.

## Fishing

Both recreational and commercial fishing occur regularly in Florida Keys waters. From a recreational standpoint, fishers are either local residents (roughly one third of Florida's total population of approximately 18 million people live in Southeast Florida or the Keys) or non-residents visiting "The Fishing Capitol of the World," as the state of Florida promotes itself (Ault et al., 2005a; FWC, 2007).

Total fishing activity in the Florida Keys reflects Florida's increasing population, which grew tenfold from 1930 to 2007 (Ault et al., 2005b). Recreational vessel registrations in Monroe County increased more than 1000% from 1964 to 2006, while commercial vessel registrations increased by about 100% from 1964 to 1998 but have since decreased by 37% (Bohnsack, et al., 1994; Figure 6.4). Precise data on fishing effort on coral reefs do not exist, but are reflected by statewide and regional fishing statistics. In the five most recent years for which recreational fishery estimates are available (2001-2005) for Florida, more than 6.4 million anglers averaged 27.2 million marine fishing trips annually. An estimated 173.3 million fish were caught annually, of which slightly more than 50% were released (86.9 million; NMFS, 2007). Two recent (2000-2001, 2003) non-concurrent studies showed that 3.64 million person days were spent fishing on natural reefs annually in the Florida Keys (Johns et al., 2001; Johns et al., 2004). Concomitant with increasing fishing pressure associated with increasing population, average fishing power (the proportion of stock removed per unit of fishing effort) may have quadrupled in recent decades because of technological advances in fishing tackle, hydroacoustics (depth sounders and fish finders), navigation (charts and global positioning systems), communications and vessel propulsion (Bohnsack and Ault, 1996; Mace, 1997).

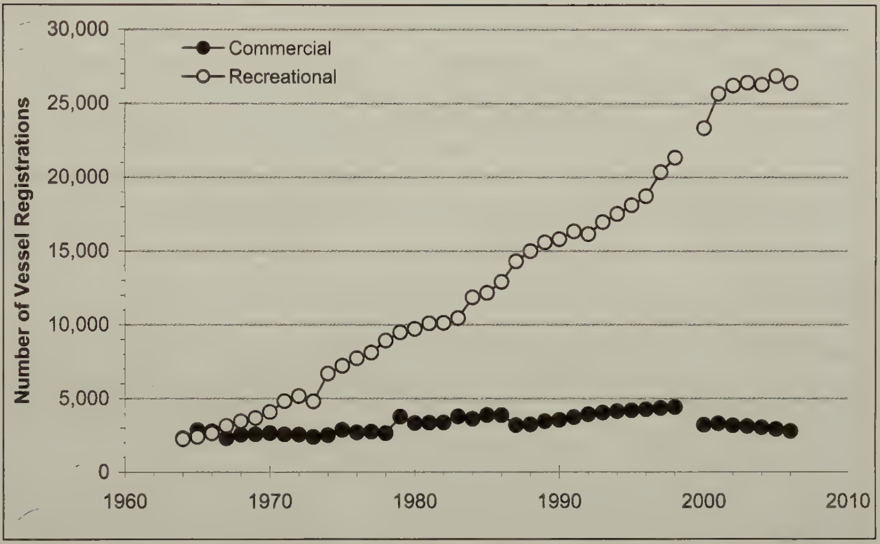


*Figure 6.4. Southern Florida (Monroe, Dade, Broward, Palm Beach and Collier Counties commercial and recreational vessel registrations from 1964 to 2007. Sources: Florida Statistical Abstracts and Florida Department of Highway Safety and Motor Vehicles.*

Fishing can stress coral reefs by removing targeted species and by killing nontarget species as bycatch, both of which may result in cascading ecological effects (Frank et al., 2005). Because fishing is size-selective, concerns exist about ecosystem disruption by removal of ecologically important keystone species, top predators (e.g., groupers, snappers, sharks and jacks), and prey (e.g., shrimps and baitfish).

Fishing can also negatively impact reef ecosystems via fishing-related habitat damage. Commercial fisheries for lobsters and stone crabs in the Keys utilize traps that are deployed in habitats adjacent to reefs. Strong storms can move traps onto reefs, where corals and other benthic organisms are damaged or killed (e.g., Sheridan et al., 2005). In 2005, approximately 300,000 lobster traps were believed to have been lost during a series of hurricanes and strong storms (Clark, 2006). Many reefs throughout the Keys are littered with lost traps and with monofilament line lost by recreational anglers. Reef damage may also occur from anglers anchoring on reefs (Davis, 1977). Finally, stress associated with fishing-related removal of species and habitat damage may be compounded when combined with other stressors such as pollution and climate change (Wilkenson, 1996).

## Trade in Coral and Live Reef Species

The trade in coral and live reef species is not considered a major direct threat to coral reef ecosystems in Florida. The collection and sale of living corals and hard substrate with attached organisms ("live rock") has been prohibited in state waters of Florida since 1995 and in federal waters since 1997. The state and federal government both regulate a small but viable fishery based in live rock aquaculture, where geologically-unique limestone is placed on the ocean floor and acts as a recruitment site for hard and soft corals and other marine invertebrates. While the fishery remains commercial in nature (mature live rock is sold in the aquarium trade), opportunities to use aquacultured live rock for mitigation or restoration may exist in the future.

Similar to live rock aquaculture, the collection and sale of live reef species comprises a small but well-managed fishery, most notably in the Florida Keys. Approximately 147 endorsements (permits) were issued for the live collection of ornamental vertebrates and invertebrates for sale in the aquarium industry in Monroe County in 2007. State-wide landings in 2005 included 147,290 total finfish and 8,611,912 individual invertebrates (e.g., polychaete worms, tunicates, crabs, sea stars and anemones). The fishery has been regulated by the state fisheries agency (currently the Florida Fish and Wildlife Conservation Commission or FWC) since 1991. Florida Keys fishermen have been exemplary in initiating regulations for their fishery and monitoring fluctuations in the variety of species they harvest. Concerned fishermen of the Keys continue to work with the FWC to suggest rule changes to ensure sustainability of the marine life fishery.

## Ships, Boats and Groundings

Vessel groundings in the Florida Keys occur regularly, and each impacts the benthic environment. The significance of these groundings, and associated restoration alternatives, was detailed in the Florida chapter of the *State of the Coral Reef Ecosystems of the United States and Pacific Freely Associated States: 2005* (Andrews et al., 2005). In the Florida Keys, the number of reported vessel groundings from years 2002 to 2006 decreased annually (721, 655, 433, 424, and 301 respectively), but it is not possible to determine if this trend is a result of fewer boaters using the resource because of higher fuel costs, increased boater awareness of the sensitivity of the environment, or a decreased willingness to call for assistance if boaters run aground. Generally, there has been no proportional shift in impact to different habitat types with approximately 14% of groundings in coral habitat, an estimated 85% in seagrass and about 1% in hardbottom.

## Marine Debris

### *Traps and "Casitas"*

During the 2005 hurricane season, the Keys were subjected to several major storms which mobilized and damaged commercial lobster and stone crab traps, making it practically impossible for fishermen to locate and retrieve their fishing gear. Florida state law (Chapter 68B-55 FAC), which normally prohibits removal of commercial traps by anyone other than their owner or law enforcement officers, threatened to hinder removal efforts. Ultimately, the state of Florida partnered with Monroe County to recover more than 45,000 traps from Monroe County waters, at a cost of more than $1.8 million. Marine debris removal also occurs on a smaller scale, as community coastal cleanup events are regularly organized throughout the year. These events help eliminate trap-related debris that has washed onto mangrove islands and beaches.

Casita is a term used to describe a particular type of fishing gear used to attract spiny lobsters elsewhere in the Caribbean. The term is Spanish in origin and translates as "little house." Within the FKNMS, casitas are not considered traditional fishing gear, and thus are subject to regulation via the National Marine Sanctuaries Act (NMSA) and the Florida Keys National Marine Sanctuary and Protection Act (FKNMSPA). As such, it is against FKNMS regulations to place casitas inside FKNMS boundaries, and it is illegal to harvest spiny lobster from any artificial structure throughout the state of Florida. Casita placement (and presumably the associated lobster harvest) is common in the backcountry area north of the Lower Keys, and there is concern among wildlife management agencies that there could be detrimental effects to natural habitat and lobster population dynamics as a result. Additionally, there are concerns in the commercial trap fishing industry that this practice is unfairly shifting fishery allocation away from the legal lobster trap fishers. In July 2007, a cooperative effort between state and federal partners was implemented to target and remove casitas in the Lower Keys. Simultaneously, fisheries biologists from the state of Florida began evaluating the effect of casitas on the ecology of the backcountry area and the lobster fishery in response to a request from FWC Commissioners.

### *Derelict and Abandoned Vessels*

In a typical year, approximately 100 boats are abandoned in the Florida Keys. In addition to this number, the 2004 and 2005 hurricane seasons caused more boats to be moved into sensitive habitats like seagrass beds and mangrove islands. After the 2005 hurricane season, Monroe County initially surveyed 355 vessels aground, but cleanup operations ultimately removed nearly 500 vessels from the water. More information on derelict and abandoned vessel removal programs can be found at http://myfwc.com/boating/DerelictVessels.htm.

## Aquatic Invasive Species

Non-native (exotic) fishes have been increasingly documented in Florida coral reef environments. These species have the potential to disrupt natural coral reef communities due to increased predation of natural species, increased competition for available space and potential introduction of diseases. More than 18 species of non-native marine fish have been documented from Miami/Dade, Broward and Palm Beach counties in Southeast Florida (REEF database, 2006). Lionfish (*Pterois volitans* and *P. miles*), which are included in this number, have become well established along the U.S. east coast, Bermuda and the Bahamas (Figure 6.5). The most likely pathway for introduction of these exotic species in Florida waters is aquarium releases (Semmens et al., 2004)

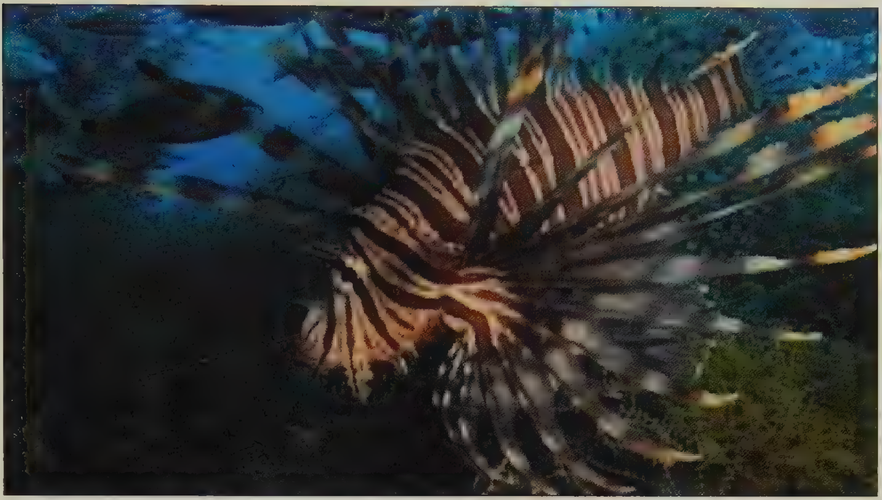


*Figure 6.5.* Pterois volitans, *one of two species of lionfish from the Pacific, has become established along the U.S. east coast. It was probably imported for use in an aquarium before being released by its owner into the wild. Photo: P. Whitfield.*

Reports of lionfish range from Rhode Island to the Turks and Caicos Islands, but as of December 2006, no sightings had been reported from Biscayne National Park, the Florida Keys or the Dry Tortugas. The northern records of lionfish sightings have been limited to juvenile fish, however the southern range appears to be expanding both spatially and in abundance. Research by NOAA's National Center for Coastal Ocean Science, Center for Coastal Fisheries and Habitat Research shows that the thermal tolerance of *P. volitans/miles* (11°C minimum) appears to preclude their adult establishment north of North Carolina (Kimball et al., 2004)). However, the increasing abundance and distribution of lionfish in the South Atlantic Bight, Bermuda, Florida and the Bahamas provides strong evidence suggesting lionfish are the first marine fish species to successfully establish a breeding population in the tropical western Atlantic. The venomous nature of lionfish, combined with their voracious feeding habits, unique reproduction and few predators, indicate successful invasive abilities. Sightings of non-native marine fish are being tracked through the REEF Volunteer Fish Survey Project in partnership with federal and state agencies in the hope of preventing additional successful invasions in Florida's marine waters.

### Security Training Activities

The 2004 closing of the Navy base in Vieques, Puerto Rico, has not resulted in the anticipated increase in military activities that threaten the coral reef ecosystems of the Florida Keys, but the U.S. Navy is increasing its readiness by improving housing, dockage and aircraft facilities in the Key West area. Plans for grading along the runways of Naval Air Station Key West are being developed that will improve safety conditions there. This construction will affect mangrove and marsh systems, but will not directly affect nearby seagrass and coral resources. In general, security training activities of the U.S. Navy and U.S. Coast Guard are not recognized as a major threat to coral reef ecosystems in Florida. Although these activities can change in response to threats to national security or the need to maintain readiness (e.g., illegal immigration from Caribbean nations), military operations usually undergo review and revision to minimize environmental impacts.

### Offshore Oil and Gas Exploration

There is currently no oil or gas drilling occurring in state waters. Florida law prohibits future leasing or drilling of the seabed within the state's Territorial Sea for purposes of oil and gas exploration and development. Holders of any offshore drilling leases that were granted by the state prior to the enactment of the current law must obtain permits under state environmental laws and regulations prior to conducting any drilling activities. No leases exist in Florida areas where coral reef tracts are located.

## CORAL REEF ECOSYSTEMS—DATA-GATHERING ACTIVITIES AND RESOURCE CONDITION

### Historical Ecology of the Florida Keys

Like reef communities worldwide, the Florida Keys have been degraded by overfishing and habitat loss. The roots of degradation pre-date scientific data collection, so historic data are needed to assess long-term change. Historical data sources range from logs kept by early Spanish and British explorers to fishing guides written by recreational fishermen in the 20th century (Figure 6.6). For example, the British cartographer, George Gauld, spent 17 years mapping the Keys in the 1760s and kept a journal where he described the reef as full of fish and wrote that, "there are such quantities of the largest [lobster], that a boat may be loaded with them in a few hours." Gauld also mapped much of the coral reefs in the Florida Keys (Figure 6.7). This kind of historical information can help to develop a baseline for understanding how the natural system functioned before human impacts.

Specific changes documented by historical ecology research include: 1) loss of top predators, such as an extinct species of monk seal which was historically ubiquitous and abundant in coral reef communities; 2) loss of spawning aggregations and reductions in numbers of large fish, such as groupers that have been intensively fished since the 18th century; 3) loss of habitat structure including mangroves, corals and seagrass; 4) reductions in invertebrate populations including conchs, lobsters and urchins; and 5) loss of ecosystem services, such as water filtration by sponges. For example, at its peak, the sponge fishery in the northern Caribbean removed six million pounds of live sponge annually (Figure 6.8). Understanding the degree of change that has occurred over time and how the ecosystem functioned in a more pristine state is essential for management and restoration of Florida's ecologically and economically important reef communities.

A number of coral reef ecosystem monitoring projects are underway in the Florida Keys, making it one of the most intensively studied coral jurisdictions in the U.S. Although no summary table of monitoring activities or map showing the distribution of monitoring locations were prepared for this chapter, many of the important ongoing activities are described below.

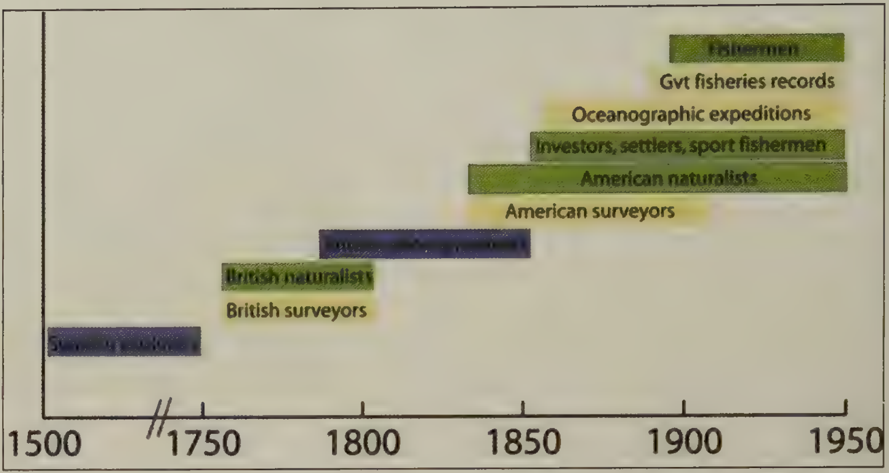


*Figure 6.6. Time line for sources of historic resource information about the Florida Keys. Source: L. McClenachan, unpub. data.*

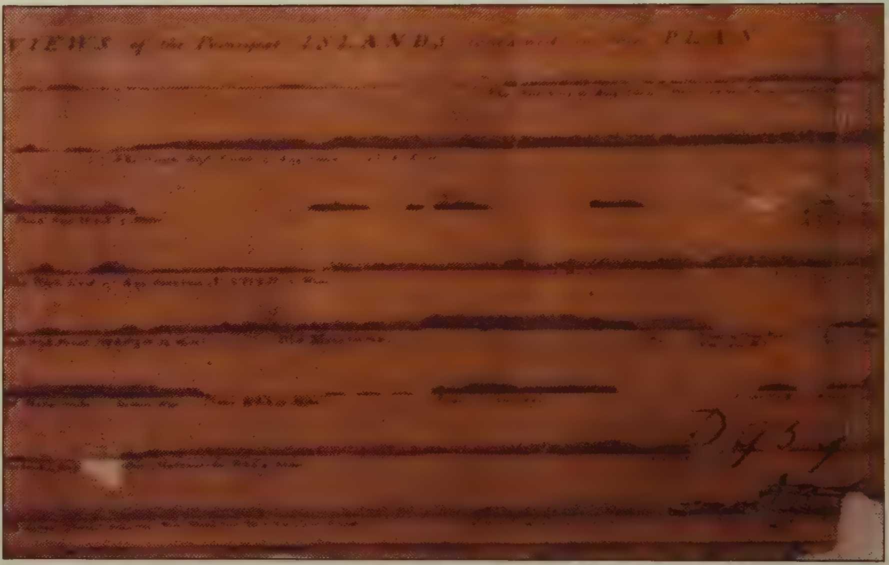


*Figure 6.7. Gauld's 1775, "A Plan for the Gulf of Florida". Source: Gauld, 1775.*

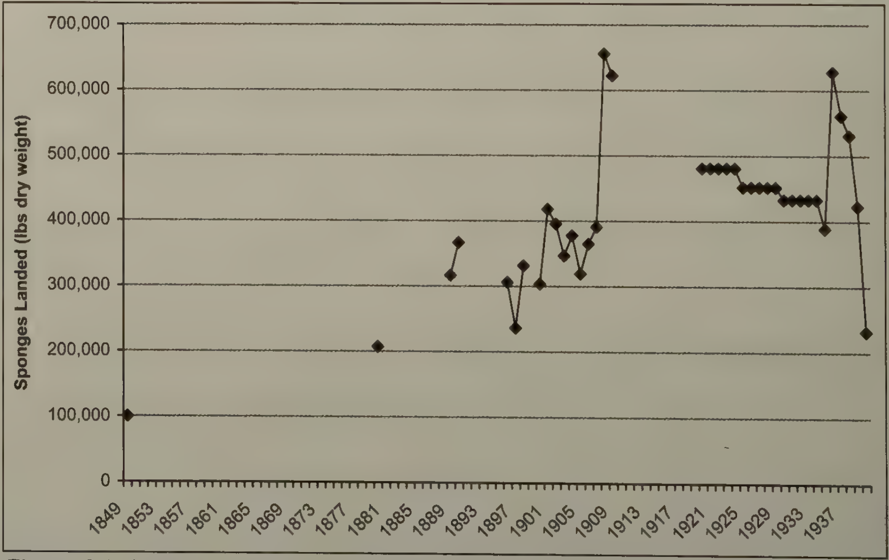


*Figure 6.8. Landings of live sponge in Florida, 1850-1940. At its peak, the fishery removed 600,000 lbs annually in dry weight, which is equivalent to approximately 6 million lbs of live sponge. Source: McClenachan, 2008.*

## WATER QUALITY AND OCEANOGRAPHIC CONDITIONS

Background and methods for this section are detailed in the Florida chapter of the previous report (Andrews et al., 2005) and the FY2006 *Annual Report of the Water Quality Monitoring Project for the Florida Keys National Marine Sanctuary* (Boyer and Briceño, 2007). Only new information and related discussion are presented in this section.

Several water quality variables were measured *in situ* and from grab samples at 154 fixed stations within the FKNMS boundary from March 1995 to December 2006 (Figure 6.9). Stations were stratified according to water quality characteristics (i.e., physical, chemical and biological variables) using multivariate statistical techniques, an approach that has been very useful in understanding the factors influencing nutrient biogeochemistry in Florida Bay, Biscayne Bay and the Ten Thousand Islands (Boyer and Briceño, 2007). Data from individual sites for the complete period of record were plotted as time series graphs to illustrate any temporal trends that might have occurred. Temporal trends were quantified by simple regression with significance set at $p<0.05$.

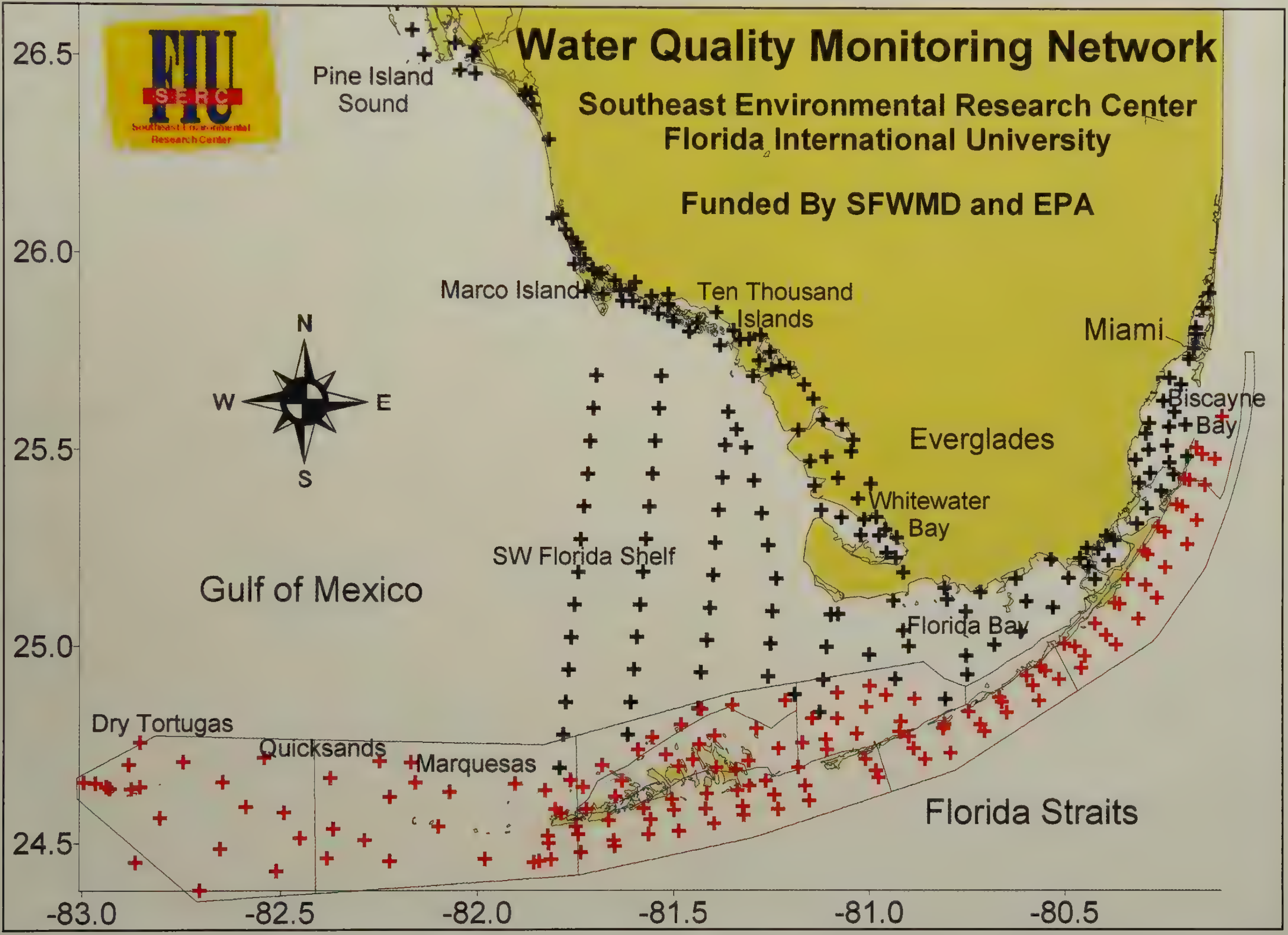

Water Quality Monitoring Network
Southeast Environmental Research Center
Florida International University
Funded By SFWMD and EPA
FIU
SERC
Southeast Environmental Research Center
Pine Island Sound
Marco Island
Ten Thousand Islands
Miami
Biscayne Bay
Everglades
Whitewater Bay
SW Florida Shelf
Gulf of Mexico
Florida Bay
Dry Tortugas
Quicksands
Marquesas
Florida Straits
N
W
E
S
26.5
26.0
25.5
25.0
24.5
-83.0
-82.5
-82.0
-81.5
-81.0
-80.5

*Figure 6.9. The Southeast Environmental Research Center (SERC) Water Quality Monitoring Network showing the distribution of fixed sampling stations, indicated by +, within the FKNMS and Florida Bay, Biscayne Bay, Whitewater Bay, Ten Thousand Islands and Southwest Florida Shelf. SFWMD=South Florida Water Management District. Source: Boyer and Briceño, 2006.*

Summary statistics for water quality variables from all 46 sampling events are shown as median, minimum, maximum and number of samples (Table 6.2). Overall, the region was warm and euhaline with a median temperature of 27.1°C and salinity of 36.2; oxygen saturation of the water column ($DO_{sat}$) was relatively high at 88.5%. On this coarse scale, Sanctuary waters exhibited very good water quality with median nitrate ($NO_3^-$), ammonium ($NH_4^+$), and total phosphorus (TP) concentrations of 0.09, 0.29, and 0.19 µM, respectively. Ammonium was the dominant dissolved inorganic nitrogen (DIN) species in almost all of the samples (about 70%). However, DIN comprised a small fraction (4%) of the total nitrogen (TN) pool with total organic nitrogen (TON) making up the bulk (median 11.2 µM). Soluable reactive phosphorus (SRP) concentrations were very low (median 0.02 µM) and comprised only 6% of the TP pool. Chlorophyll a (CHLA) concentrations were also very low overall, 0.23 µg $l^{-1}$, but ranged from 0.01 to 15.2 µg $l^{-1}$. Total organic carbon (TOC) was 178.0; a value higher than open ocean levels but consistent with coastal areas. Median turbidity was low (0.63 nephelometric turbidity units or NTU) as reflected in a low light extinction coefficient or Kd value of 0.204 $m^{-1}$. This resulted in a median photic depth (to 1% incident photosynthetically active radiation or PAR) of approximately 22 m. Molar ratios of nitrogen (N) to phosphorus (P) suggested a general P limitation of the water column (median TN:TP=61.6) but this must be tempered by the fact that much of the TN is not bioavailable.

Several important results have been realized from this monitoring project. The first is the documentation of elevated DIN in the nearshore zone of the Florida Keys (Figure 6.10). This result was evident from our first sampling event in 1995 and continues to be a characteristic of the ecosystem. Interestingly, this gradient was not observed in a comparison transect from the Tortugas. This type of distribution implies an inshore source which is diluted by low nutrient Atlantic Ocean waters. Presence of a similar gradient in TOC and decreased variability in salinity from land to reef also support this concept. There were no trends in either TP or CHLA with distance from land.

Another observation is that the backcountry exhibits elevated levels of DIN, TOC, turbidity, TP and CHLA (Figure 6.11). These distributions are driven by the southwest Florida shelf waters moving through this area (median DIN=0.7 µM, TOC=298 µM, Turbidity=6.4 NTU, TP=0.48 µM, and CHLA=1.6 µg l$^{-1}$). In addition to south west Florida Shelf influence, elevated $NO_3^-$ is a regular feature of backcountry waters, where some of the highest concentrations are observed in non-populated areas and is probably the result of the benthic flux of nutrients in this very shallow water column.

The third result is that TP concentrations drive phytoplankton biomass (Figure 6.12). Highest CHLA concentrations are seen on the southwest Florida shelf with a strong gradient towards the Marquesas and Tortugas. This is due to higher TP concentrations as a result of southward advection of Gulf of Mexico waters along the coast with entrainment of coastal rivers and runoff.

Finally, trends in water quality showed most variables to be relatively consistent from year to year, with some showing seasonal excursions. Overall, there were statistically significant decreases in DIN, TON (except for increases in Tortugas), TP, TOC and DO throughout the region (Figure 6.13). This is contrary to some of the trend analyses reported in previous years.

Large changes have occurred in FKNMS water quality over time, and some sustained monotonic trends have been observed (Figure 6.13). However, trend analysis is limited to the window of observation; trends may change or even reverse, with additional data collection. This brings up another important point; when looking at what are perceived to be local trends, we find that they seem to occur across the whole region but at more damped amplitudes. This spatial autocorrelation in water quality is an inherent property of highly interconnected systems such as

*Table 6.2. Values and sample stations (n) for water quality variables measured in the FKNMS, March 1995 and December 2006. Source: Boyer and Briceño, 2006.*

| VARIABLE | DEPTH | MEDIAN | MIN | MAX | *n* |
|---|---|---|---|---|---|
| Nitrate (µM) | Surface | 0.09 | 0.00 | 5.90 | 6385 |
| | Bottom | 0.08 | 0.00 | 5.01 | 3884 |
| Nitrite (µM) | Surface | 0.04 | 0.00 | 0.71 | 6394 |
| | Bottom | 0.04 | 0.00 | 1.73 | 3891 |
| Ammonium (µM) | Surface | 0.29 | 0.00 | 10.32 | 6391 |
| | Bottom | 0.25 | 0.00 | 3.88 | 3886 |
| Total Nitrogen (µM) | Surface | 11.76 | 0.73 | 213.21 | 6387 |
| | Bottom | 9.84 | 0.88 | 153.75 | 3857 |
| Total Organic Nitrogen (µM) | Surface | 11.19 | 0.00 | 212.89 | 6363 |
| | Bottom | 9.31 | 0.00 | 153.43 | 3830 |
| Total Phosphorus (µM) | Surface | 0.19 | 0.00 | 1.78 | 6396 |
| | Bottom | 0.17 | 0.00 | 1.50 | 3871 |
| Soluble Reactive Phosphorus (µM) | Surface | 0.02 | 0.00 | 0.56 | 6379 |
| | Bottom | 0.02 | 0.00 | 0.39 | 3879 |
| Alkaline Phosphatase Activity (µM h$^{-1}$) | Surface | 0.06 | 0.00 | 5.62 | 6230 |
| | Bottom | 0.05 | 0.00 | 0.50 | 3724 |
| Chlorophyll a (µg l$^{-1}$) | Surface | 0.23 | 0.00 | 15.24 | 6395 |
| Total Organic Carbon (µM) | Surface | 178.01 | 18.38 | 1653.5 | 6388 |
| | Bottom | 151.13 | 0.00 | 2135.8 | 3867 |
| Silicate (µM) | Surface | 0.64 | 0.00 | 127.11 | 6089 |
| | Bottom | 0.42 | 0.00 | 30.20 | 3692 |
| Turbidity (NTU) | Surface | 0.63 | 0.00 | 37.00 | 6350 |
| | Bottom | 0.50 | 0.00 | 16.90 | 3907 |
| Salinity (ppt) | Surface | 36.2 | 26.7 | 40.9 | 6306 |
| | Bottom | 36.2 | 27.7 | 40.9 | 6275 |
| Temperature (°C) | Surface | 27.1 | 15.1 | 39.6 | 6313 |
| | Bottom | 26.7 | 15.1 | 36.8 | 6282 |
| Dissolved Oxygen (mg l$^{-1}$) | Surface | 5.9 | 0.1 | 14.5 | 6278 |
| | Bottom | 6.0 | 1.4 | 13.9 | 6229 |
| Light Attenuation Coefficient (m$^{-1}$) | | 0.204 | 0.000 | 4.084 | 4363 |
| Dissolved Oxygen Saturation (%) | Surface | 88.5 | 1.2 | 226.2 | 6277 |
| | Bottom | 88.7 | 19.3 | 207.0 | 6227 |
| Water Column Stratification (kg m$^{-3}$) | | 0.01 | -4.42 | 6.64 | 6256 |

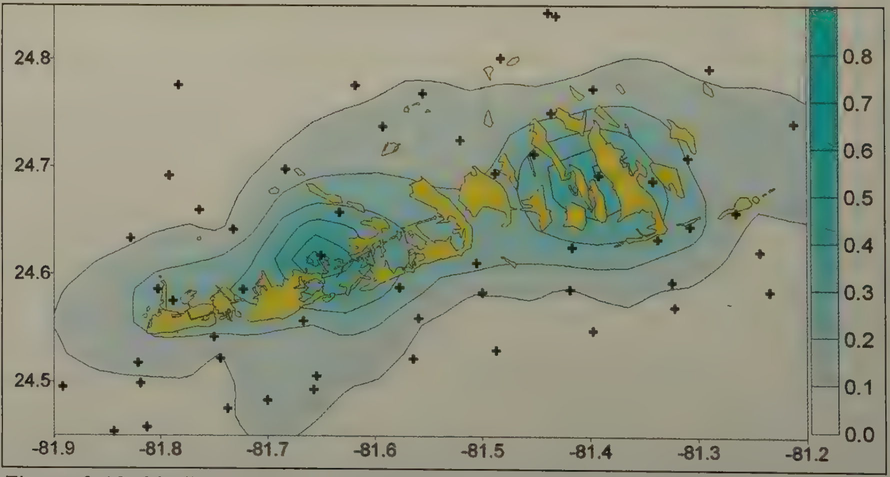


*Figure 6.10. Median nitrate concentrations (µM) in the Backcountry for the period 1995 to 2005. Source: Boyer and Briceño, 2006.*

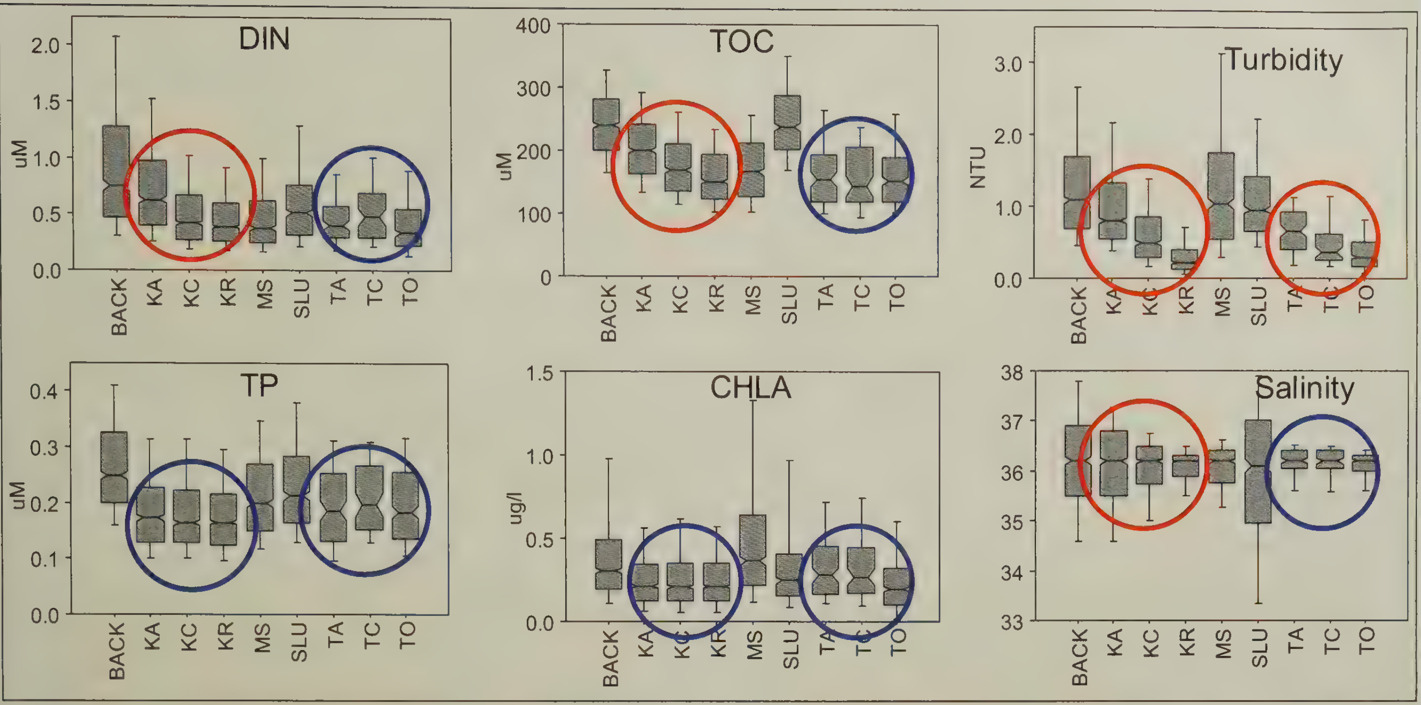


*Figure 6.11. Nutrient concentration gradients from alongshore to offshore in Keys reef tract and Tortugas. Red circles denote significant gradient. Box plot shows data distribution and median (notch) of Keys Alongshore (KA), Hawk Channel (KC), and Reef Tract (KR) as well as Tortugas Alongshore (TA), Channel (TC) and Offshore (TO). Source: Boyer and Briceño, 2006.*

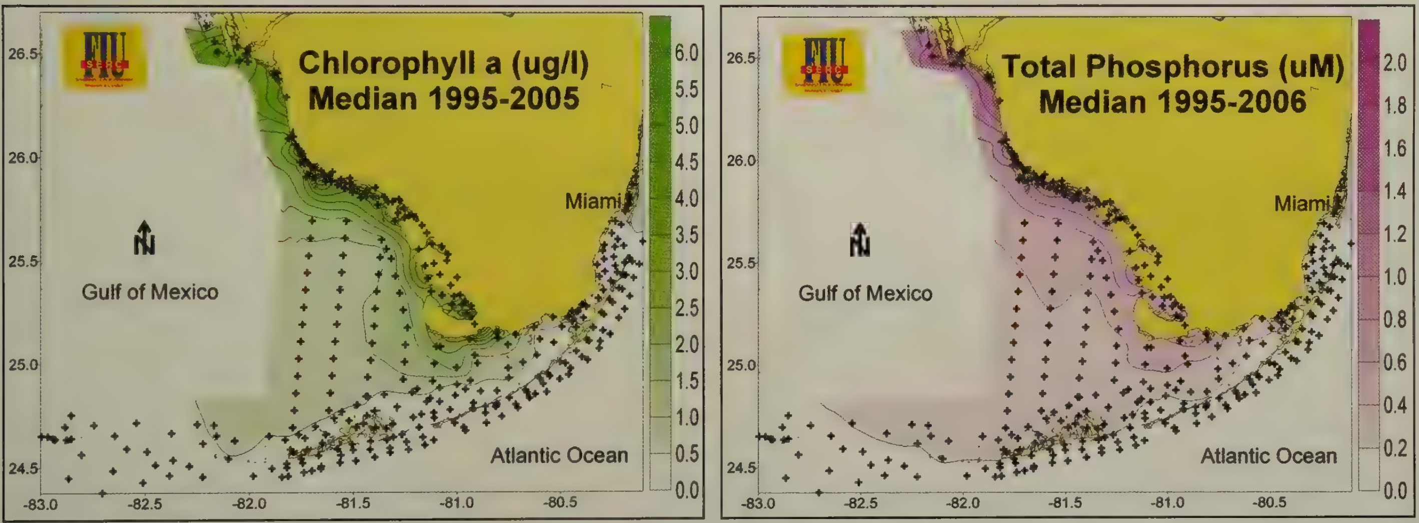


*Figure 6.12. Distribution of median concentrations of CHLa (left panel) and TP (right panel) in Florida's coastal waters for the period 1995 to 2005. Sampling stations are indicated with a plus (+) symbol. Source: Boyer and Briceño, 2006.*

coastal and estuarine ecosystems driven by similar hydrological and climatological forcings. It is clear that trends observed inside the FKNMS are influenced by regional conditions outside Sanctuary boundaries.

The large scale of this monitoring program has allowed a holistic view of broad physical/chemical/biological interactions occurring over the South Florida region. Much information has been gained by inference from this type of data collection program; major nutrient sources have be confirmed, relative differences in geographical determinants of water quality have been demonstrated and large-scale transport via circulation pathways has been elucidated. In addition, this program demonstrates the importance of looking "outside the box" for questions asked within. Rather than thinking of water quality monitoring as a static, non-scientific pursuit, it should be viewed as a tool for answering management questions and developing new scientific hypotheses. Downloadable contour maps, time series graphs and interpretive reports from the Southeast Environmental Research Center's Water Quality Monitoring Network (which includes Florida Bay, Whitewater Bay, Biscayne Bay, Ten Thousand Islands and Southwest Florida Shelf) are available at http://serc.fiu.edu/wqmnetwork .

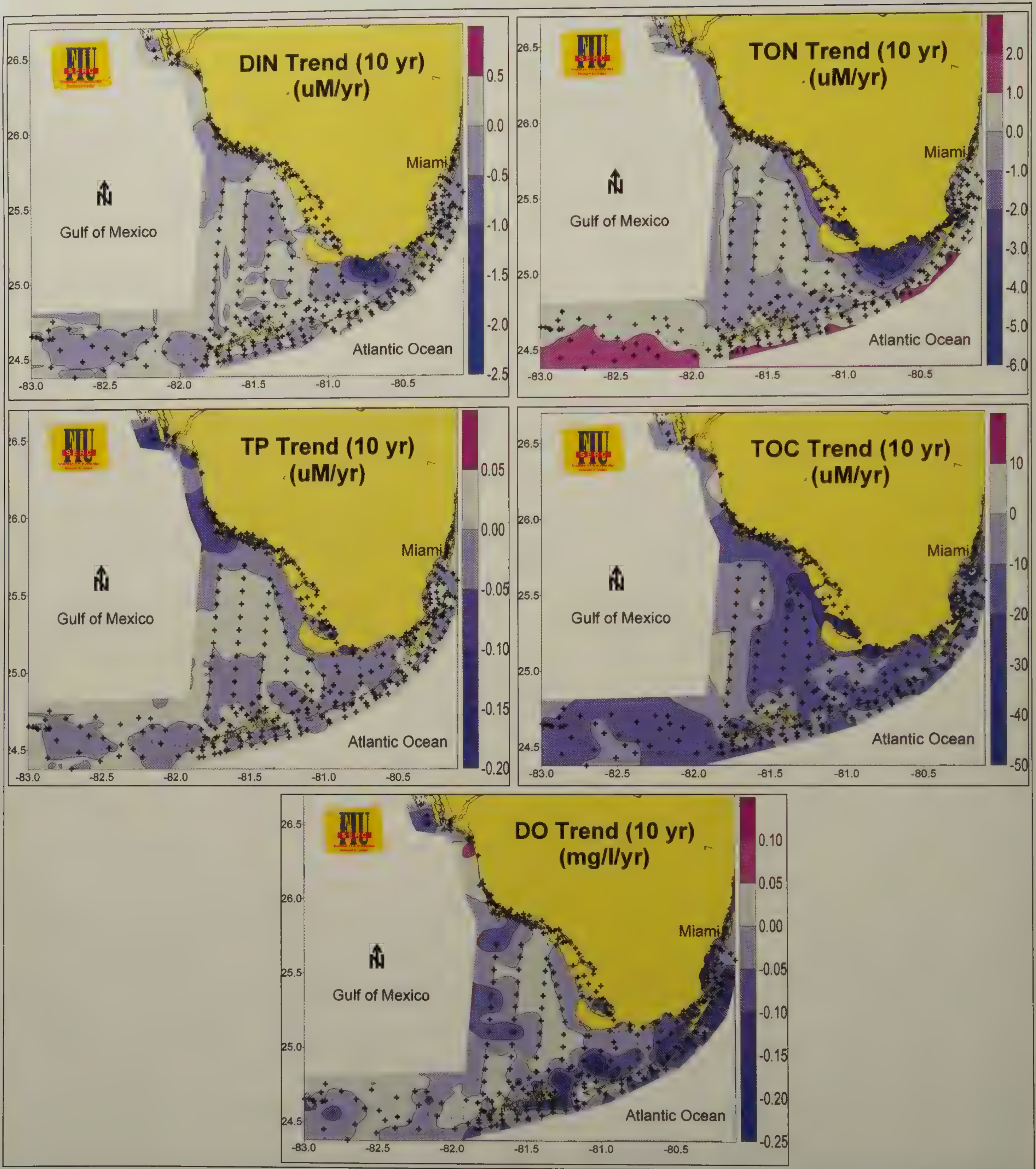

DIN Trend (10 yr) (uM/yr)
TON Trend (10 yr) (uM/yr)
TP Trend (10 yr) (uM/yr)
TOC Trend (10 yr) (uM/yr)
DO Trend (10 yr) (mg/l/yr)
Gulf of Mexico
Atlantic Ocean
Miami
N
0.5
0.0
-0.5
-1.0
-1.5
-2.0
-2.5
2.0
1.0
-2.0
-3.0
-4.0
-5.0
-6.0
0.05
0.00
-0.05
-0.10
-0.15
-0.20
10
0
-10
-20
-30
-40
-50
0.10
-0.25
26.5
26.0
25.5
25.0
24.5
-83.0
-82.5
-82.0
-81.5
-81.0
-80.5

*Figure 6.13. Trends in water quality variables throughout the region from 1995 to 2005. Slopes of individual regressions at each station are plotted. Significant decreasing trends are shown in blue while increasing trends are in pink. Sampling stations are indicated with a plus (+) symbol. Source: Boyer and Briceño, 2006.*

## BENTHIC HABITATS

### Coral Reef Evaluation and Monitoring Project (CREMP)

The Florida Fish and Wildlife Research Institute collects annual data on the status of coral habitats in the Florida reef tract through the CREMP. In 1996, data collection began at 40 sites in the Florida Keys. The project was expanded in 1999 to include three sites in the Dry Tortugas. In 2003, 10 additional sites were selected at reefs along Florida's southeast coast and have been monitored annually under the Southeast Florida CREMP (SECREMP) project; the results of the SECREMP work are reported in the Southeast Florida chapter of this report.

CREMP sites encompass four reef habitat categories: hardbottom, patch reef, and offshore deep and shallow reefs. Sites are comprised of two to four permanent stations. Data collection at each station includes an inventory of stony coral species, video transects to assess percent cover of stony coral species and selected benthic functional groups (calculated from images extracted from video), a qualitative assessment of disease and bleaching and a bioeroding sponge survey. Details on sampling design, field methods and data processing and analyses are available at http://ocean.floridamarine.org. Previous reports have documented trends from the project initiation until 2002 (Andrews et al., 2005). This summary will focus on changes observed in coral communities between 2002 and 2005.

Stony coral species richness within the CREMP stations showed a general decline across all habitat types between 1996 and 1999 (Figure 6.14). Between 2005 and 2006, the data show a greater decline in species richness at deep offshore and hardbottom sites than at shallow offshore or patch reef sties in the FKNMS. Some of the smaller or less common species have declined in distribution. For example, in 2006, *Favia fragum*, *Mycetophyllia lamarckiana*, *Leptoseris cucullata* and *Eusmilia fastigiata* were observed in approximately half of the stations in which they were recorded in 2005. Overall there has been a net loss in species richness within the FKNMS since the project's inception. Coral cover at reefs that were historically dominated by acroporid species (*Acropora cervicornis* or *A. palmata*) have been largely reduced to rubble from disease and hurricanes. The Dry Tortugas has historically supported some of the largest populations of *A. cervicornis* in Florida, creating large *Acropora*-dominated patch reefs (Davis, 1982). One of the most luxurious of these acroporid reefs was White Shoal patch reef where coral rubble now comprises a large portion of the substrate. *A. cervicornis* populations in the Dry Tortugas have decreased since the beginning of monitoring in 1999.

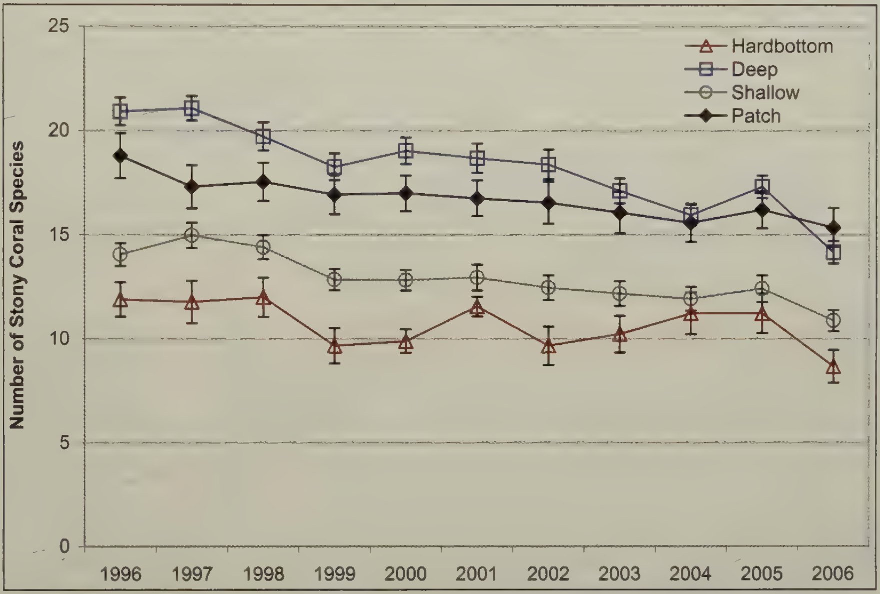


*Figure 6.14. Mean number of stony coral species by habitat within the FKNMS. Hardbottom (n=9), deep reefs (n=26), shallow reefs (n=39), patch reefs (n=29). Error bars represent standard error of the mean. Source: CREMP.*

The relative mean percent cover of stony corals in the FKNMS declined between 1996 and 1999, but was relatively stable from 1999 to 2005 (Figure 6.15). Additionally, between 2005 and 2006 there was a consistent loss of stony coral cover in all regions and habitats sampled in the FKNMS, with the deep offshore reefs showing the greatest decline. This observed decline is likely attributable to loss of cover of the boulder star coral, *Montastraea annularis*. This framework builder has been the dominant species in terms of percent cover and occurrence throughout the sites sampled in the Florida Keys reef system, and has been in decline throughout the duration of the monitoring project.

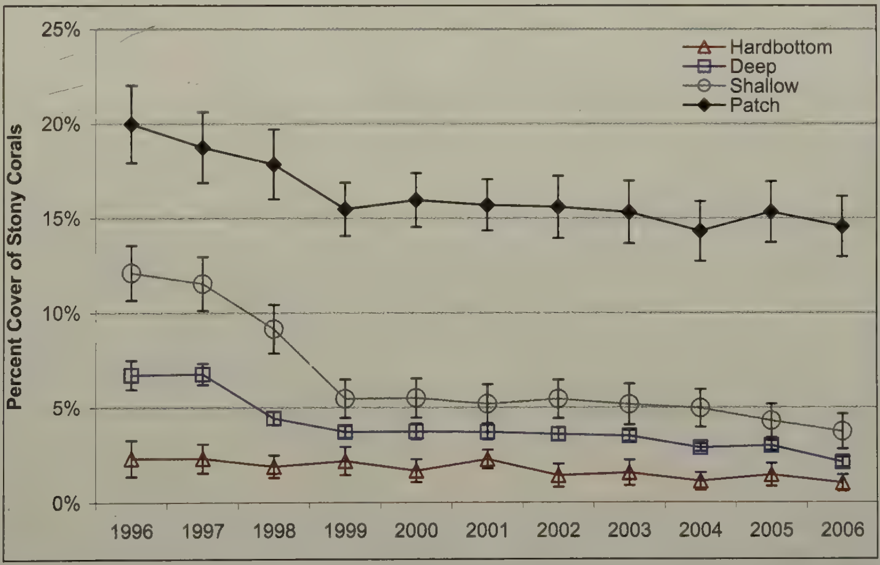


*Figure 6.15. Mean percent cover of stony corals by habitat within the FKNMS. Hardbottom (n=9), deep reefs (n=26), shallow reefs (n=39), patch reefs (n=29). Error bars represent standard error of the mean. Source: CREMP.*

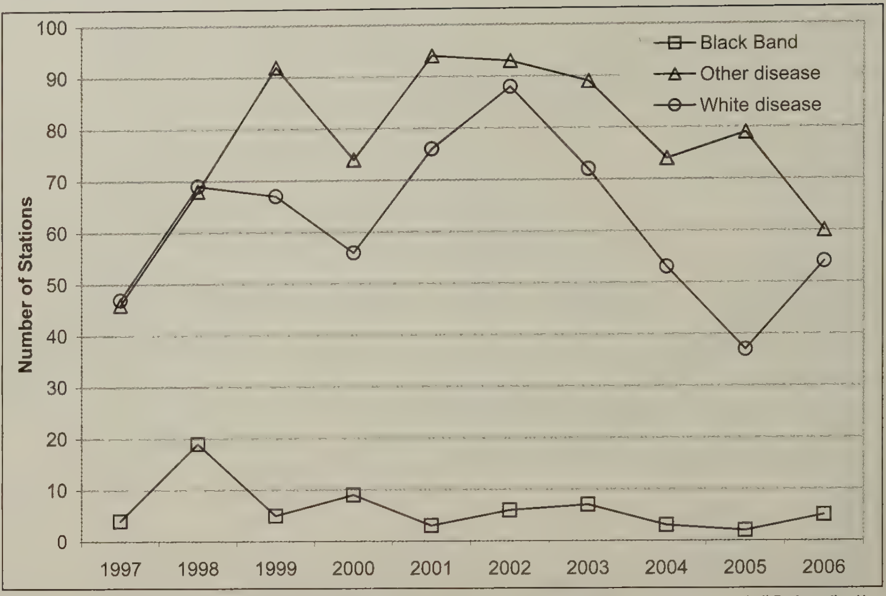


*Figure 6.16. Occurrence of Black Band disease, White disease and "Other" disease by station within the Florida Keys National Marine Sanctuary (n=103 stations). Source: CREMP.*

The hurricanes and tropical storms that affected Florida in 2004-2005 undoubtedly impacted coral habitats. At such a high frequency of occurrence, there has been minimal time for recovery between storms. In 2005, hurricanes Dennis, Katrina, Rita and Wilma each passed over some part of the Florida reef tract. In some locations, structural damage to reefs can be attributed to storm effects; however, storm damage may not always be obvious. Strong waves move sand that can scour or temporarily suffocate corals, causing tissue loss without structural destruction. The summer of 2005 was also marked with periods of unusually calm conditions, which in combination with elevated temperatures (>31°C) caused a severe bleaching event in the Florida Keys. Ironically, the hurricanes also caused the water temperatures to drop below critical bleaching temperatures. The combination of hurricanes and severe bleaching in 2004/2005 is likely primarily responsible for the observed decrease in stony coral species richness and percent cover at the CREMP monitoring sites in 2006. However, the offshore deep sites, which might be expected to be buffered by the effects of hurricanes and bleaching, showed the greatest loss between 2004 and 2006. Since 2002, disease has generally decreased within the CREMP stations within the FKNMS. Diseases can be difficult to distinguish in the field since different pathogens can produce similar symptoms. For CREMP, the white diseases (white plague, white pox, white band) are placed in one category, black band in another, and the remainder in an "Other" category. The number of stations affected with white diseases peaked to more than 80% in 2002, subsided to 35% in 2005, then increased again to 50% in 2006. The number of stations affected with "Other" diseases peaked to 90% in 2001, but declined to 57% by 2006 (Figure 6.16). These data provide information on prevalence, but not on infection rates within the stations. Also, the absence of the disease may indicate the death of colonies that had previously been reported as infected. Despite these caveats, the data indicate that stony coral diseases generally declined from 2002 levels in the Florida Keys.

Throughout their development, coral reefs have experienced acute (and sometimes catastrophic) events such as anomalous bleaching and hurricanes. Between these events, healthy reefs begin to recover, albeit slowly. However, since monitoring began, the CREMP has not documented significant increases in coral cover at any of the study sites. This lack of recovery could be attributed to chronic environmental changes, from cumulative effects of hurricanes, severe bleaching and disease outbreaks, or a synergy of both chronic and acute impacts. Distance from human habitation has been considered a buffer from the affects of anthropogenic impacts; however, globally there are many examples of reefs that are remote from civilization and are similarly in decline.

### Acroporid Species in the Upper Keys

The declines in abundance of two of the principal Caribbean reef-building corals, staghorn (*A. cervicornis*) and elkhorn coral (*A. palmata*), are often-cited examples of the changes in western Atlantic reefs that have occurred over the past several decades (Aronson and Precht, 2001; Gardner et al., 2003). The causes of these declines, which began in the late 1970s, include large-scale factors such as coral bleaching and disease, especially white band disease, as well as smaller scale effects related to storms and predation from corallivorous snails and damselfishes. Both corals have been under consideration for addition to the U.S. Endangered Species List since the early 1990s and were formally added to the list as threatened in 2006 based upon Caribbean-wide population declines and poor recovery.

To help support NOAA's efforts to ascertain the current status of both Acroporid corals, scientists from the Center for Marine Science, University of North Carolina-Wilmington (UNCW) undertook an intensive assessment of the spatial distribution, colony abundance, size, and condition of staghorn and elkhorn corals in a portion of the FKNMS. During August 1-18, 2006, a total of 107 sites were surveyed in the upper Keys region of the FKNMS from the southern boundary of Biscayne National Park to offshore of Tavernier, a distance of approximately 46 km along the Florida reef tract (Figure 6.17). The 2006 surveys were an outgrowth of previous efforts conducted by UNCW dating back to 1999 to quantify the abundance and condition of coral reef benthos throughout the FKNMS, including the Tortugas region. Previous surveys from southwest of Key West to Biscayne National Park include 80 sites sampled in 1999, 45 sites in 2000, 108 sites in 2001, and 195 sites in 2005; more than 100 sites were also surveyed in the Tortugas region. In 2007, the program was expanded throughout the Florida Keys. More information and project results can be found at http://people.uncw.edu/millers/.

The objectives of the sampling design in the upper Keys region of the FKNMS were to provide information on:

- Habitat-based presence-absence distribution patterns encompassing diverse hard-bottom and coral reef habitat types from 1 to 15 m depth, including a photographic archival record of where both species were found;
- Colony density by site, habitat type and protection level that incorporated all of the existing FKNMS no-take marine reserves in the upper Keys;
- Size distribution of colonies in terms of tissue surface area relative to habitat type;
- Prevalence of colony conditions (normal/healthy, bleaching, disease, predation);
- Population abundance estimates for both species that is habitat and size structured; and
- Density and size of urchins, a continuing effort to monitor recovery of the historically abundant *Diadema antillarum.*

### *Results and Discussion*

*A. cervicornis* was observed in the general survey area at 19 of the 107 sites (18%) and was recorded within belt transect boundaries at 16 sites. The habitat distribution of this coral was limited to five of the eleven habitat types sampled: mid-channel patch reefs (four of 14 sites, 29%), offshore patch reefs (10 of 23 sites, 43%), shallow (<6 m) low-relief hard-bottom (one of nine sites, 11%), inner line reef tract spur and groove (one of eight sites, 13%), and high-relief spur and groove (three of 17 sites, 18%). A total of 71 staghorn coral colonies were counted within the belt transect boundaries in five of the habitat types. Of these, five colonies (7.0%) were counted from 14 mid-channel patch reefs (13.1% of sampling effort), 47 colonies (66.2%) from 23 offshore patch reefs (21.5% of sampling effort), 10 colonies (14.1%) from nine shallow (<6 m) low-relief hard-bottom (8.4% of sampling effort), four colonies (5.6%) from eight inner line reef tract spur and groove sites (7.5%), and five colonies (7.0%) from 17 high-relief spur and groove sites (15.9%). These data indicate that the distribution patterns of staghorn coral were not proportional to the sampling effort and thus suggest a preferential distribution of this coral. A greater number of colonies than expected (if the habitat distribution is random) were recorded from the two patch reef habitat types, while fewer colonies than expected were recorded from high-relief spur and groove and six of the other habitat types where no colonies were recorded. The greatest mean (± 1 SD) site level densities of 0.333 ± 0.667 colonies/m$^2$ and 0.183 ± 0.240 colonies/m$^2$ were recorded from two offshore patch reefs, one in the western area of Carysfort/S. Carysfort Sanctuary Preservation Area (site #83), the other on Mosquito Bank (site #26; Figure 6.18). Overall habitat-level densities were greatest on offshore patch reefs (0.034 ± 0.079 colonies/m$^2$).

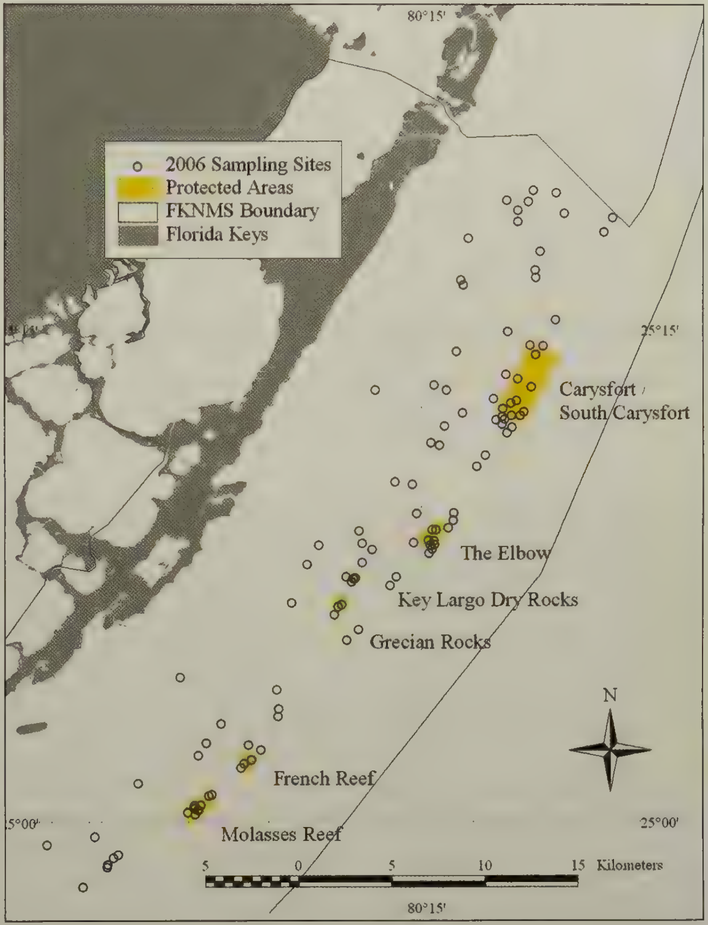


*Figure 6.17. In 2006, surveys for Acroporid corals were conducted at 107 sites in the northern FKNMS. Source: Miller et al., 2006b.*

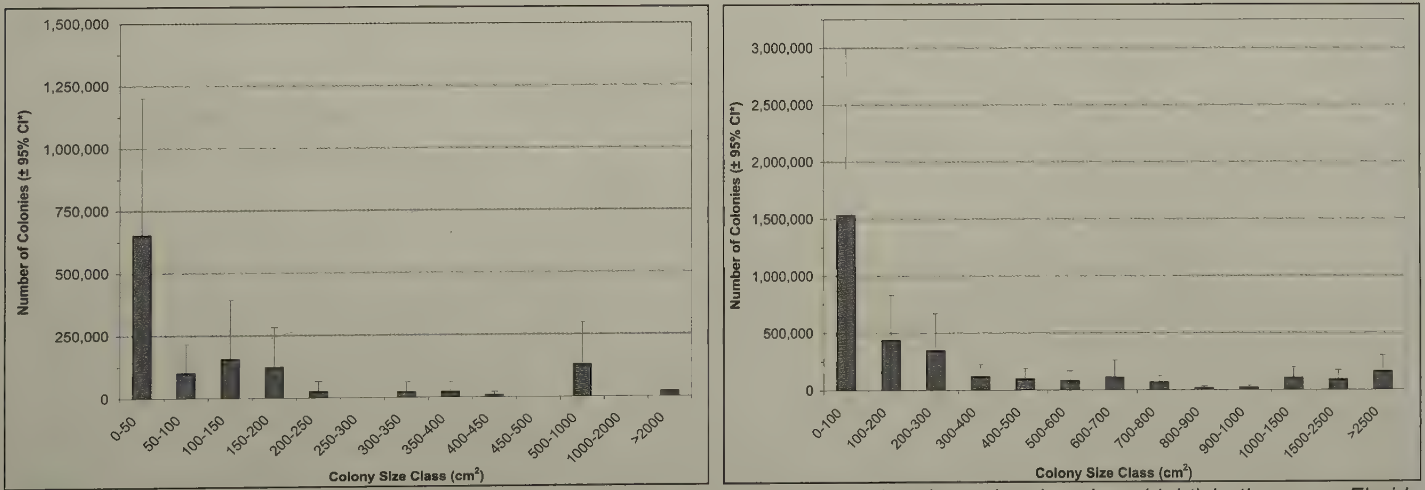


*Figure 6.18. Mean colony density of* Acropora cervicornis *(left) and* A. palmata *abundance by size class (right) in the upper Florida Keys during 2006, as determined from surveys of four 15-m x 1-m transects per site at 107 sites from northern Key Largo to Tavernier, Florida. Error bars represent one standard error. Colonies were considered to be continuous patches of live tissue. Source: Miller et al., 2006b.*

No staghorn coral thickets larger than approximately 0.5 m in diameter were observed at any location, and most sites with living staghorn coral colonies consisted of mostly small branches. Colony size (live tissue surface area) ranged from 7.4 $cm^2$ to 127.5 $cm^2$ and was largest on mid-channel patch reefs and inner line reef tract spur and groove. Nearly 90% of the sampled colonies were less than 100 $cm^2$ in surface area. Of the staghorn colonies measured, only one colony from the 77 assessed (1.4%) at all sites had obvious signs of damselfish predation. No incidences of white band, white pox or lesions were recorded for staghorn coral during the surveys.

*A. palmata* was observed at 18 of the 107 sites (17%) and was recorded within belt transect boundaries at 15 sites. The habitat distribution of this coral was limited to four of the eleven habitat types sampled: offshore patch reefs (two of 23 sites, 9%), shallow (<6 m) low-relief hard-bottom (one of nine sites, 11%), inner line reef tract spur and groove (six of eight sites, 75%), and high-relief spur and groove (nine of 17 sites, 53%). A total of 388 elkhorn coral colonies were counted within the belt transect boundaries in four of the 11 habitat types sampled. Of these, 51 colonies (13.0%) were counted from among 23 offshore patch reefs (21.5% of sampling effort), 15 colonies (3.9%) from nine shallow (<6 m) low-relief hard-bottom (8.4% of sampling effort), 100 colonies (25.8%) from eight inner line reef tract spur and groove sites (7.5%) and 222 colonies (57.2%) from 17 high-relief spur and groove sites (15.9%). Clearly the distribution pattern of elkhorn coral with respect to habitat type was not proportional to the sampling effort, indicating a preferential habitat distribution. A greater number of colonies than expected (if the habitat distribution is random) were recorded from inner line reef tract and high-relief spur and groove habitat types. The greatest mean (± 1 SD) site level densities were recorded from high-relief spur and groove reefs at South Carysfort (site #79, 1.967 ± 2.593 colonies/$m^2$) and Sand Island (site #66, 1.100 ± 1.343 colonies/$m^2$) and an inner line reef tract site at Horseshoe Reef (site #241, 0.933 ± 1.652 colonies/$m^2$). Overall habitat-level densities were greatest on high-relief spur and groove and inner line reef tract habitat types.

Elkhorn coral colony sizes showed a significantly greater range compared to its congener, and several sites with large (>0.5 m diameter) colonies were recorded. Colony sizes (live tissue surface area) ranged from 46.3 $cm^2$ to over 2,000 $cm^2$ and were greatest on high-relief spur and groove and inner line reef tract habitats. Of the 387 colonies measured, 46% were smaller than 100 $cm^2$ in surface area, while about 16% were greater than 500 $cm^2$ in surface area. While most colonies were less than 100 $cm^2$ in tissue surface area, larger colonies were also relatively common.

Of the elkhorn colonies measured, the most obvious impacts to live tissue were predation by snails (*Coralliophila abbreviata*) and damselfishes (family Pomacentridae). Lobster trap rope was found entangled in thickets of live colonies at South Carysfort Reef, but in general there was an absence of visible diseases such as white band and white pox. Of the 388 colonies assessed for disease and predation, none were found with any visible symptoms of white band, white pox or tissue necrosis. For all sites and habitats combined, 13 colonies (3.4%) were impacted by snail predation and 11 colonies (2.8%) had visible lesions from damselfish predation.

### *Demographic Monitoring Of* Acropora Palmata *In The Upper Keys*

There are many monitoring studies presently in place to assess the general status and trends of Caribbean coral reefs. *A. palmata* is often poorly represented in these studies since its natural distribution is along the reef crest and many studies focus survey efforts on fore reef areas. Furthermore, these studies typically survey randomly placed transects which are not well suited to capture information on *A. palmata's* presently sparse and highly patchy distribution. As a result, very small numbers of *A. palmata* colonies end up in the being counted in general reef monitoring studies. While this accurately depicts the present densities of *Acropora*, it yields very little information on the condition and fate of these remaining colonies. A targeted demographic (i.e., colony-based) monitoring approach (Williams et al., 2006) was used to track the performance of randomly selected "individual" colonies over time. In this way, the relative importance of the many sources of mortality for populations of *A. palmata* can be determined because combining the prevalence of a particular threat with the subsequent fate of affected colonies (or lethality) will show the ecological importance of the various threats. Thus, randomly selected colonies are tagged, measured (two diameters and height), photographed, and scored based on the estimated percent of live tissue and the presence and severity of a particular list of "threat" conditions on a regular basis. The "amount of live coral" is estimated by a Live Area Index (LAI) = [mean of 3 colony dimensions]$^2$ x [% of colony with live tissue]) for each colony and summed for the colonies at each site. A total of 192 colonies in 15 plots (7 m radius) were tagged at five reefs in the upper keys (between Carysfort and Molasses reefs) in early 2004. Surveys were conducted quarterly through 2006.

#### *Results and Discussion*

Overall, *A. palmata* populations in the upper Florida Keys display a declining trajectory between 2004 and 2006 with particularly acute losses observed during summer and fall of 2005 (overall approximately 50% loss; Williams and Miller, 2006; Figure 6.19). These losses resulted from hurricane effects and subsequent disease impacts. It should be noted that this observed decline is based on an already critically depressed baseline value measured in 2004 (Miller, 2002).

Slight recovery has been observed between fall 2005 and summer 2006, though 37 colonies have suffered complete mortality and 31 were physically removed by the hurricanes. Although the fragments generated from colonies that were substantially broken or completely removed could potentially yield new colonies (asexual recruits), approximately 70% of the 369 fragments counted after the passage of Hurricane Dennis were dead or loosing tissue rapidly. Recovery of live *A. palmata* has resulted primarily from re-growth of remnant crusts (Figure 6.20), including the formation of new branches. Less than 5% of the fragments observed in the study plots have successfully reattached and survived to date, and only one recruit that is believed to be of sexual origin has been observed. Thus, total recruitment appears to be low and does not offset the observed losses in the tagged colonies.

Demographic monitoring relies on tracking the performance of individual colonies to document the threats they face and their fate over time. For example, parrotfish bites may be extremely common among a population, but if effects on a colony are minor, they may be relatively unimportant to the viability of the population. Management and conservation resources can be more effectively applied based on an understanding of the relative impacts of threats on populations. Unfortunately, between 2004 and 2006, relatively "unmanageable" threats (hurricanes and disease) have accounted for substantial losses of live coral tissue including entire colony mortality. This emphasizes the imperative for management and conservation resources (i.e., funding) to support immediate research efforts to determine the proximal and ultimate causes of disease impacts and to identify corrective actions to mitigate disease losses for all Caribbean corals, but particularly Caribbean acroporids.

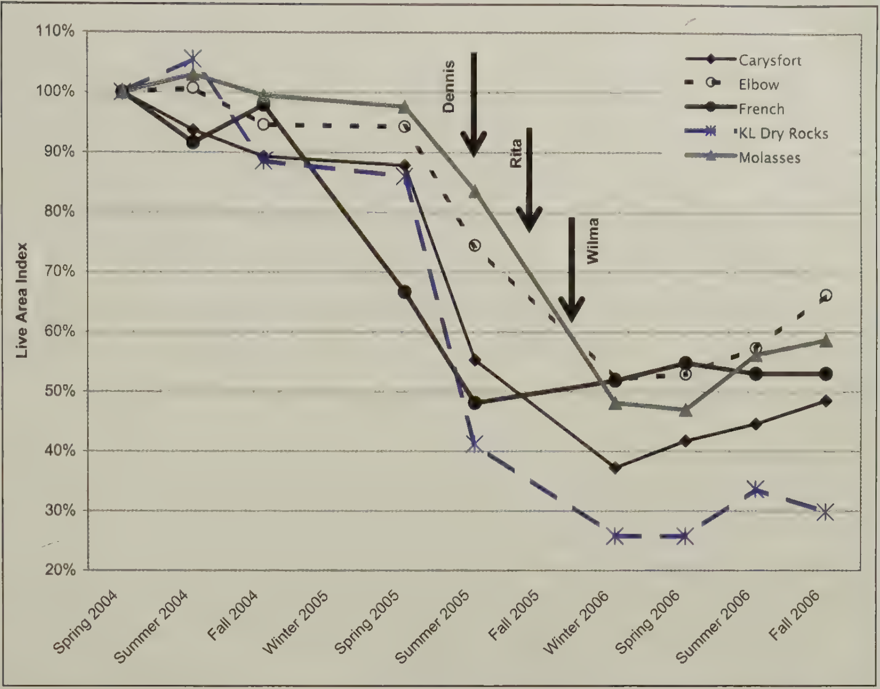


*Figure 6.19. Trend in* Acropora palmata *LAI between 2004 and 2006 in the upper Florida Keys National Marine Sanctuary. Each line represents mean percent of the original sum of LAI for 10-12 tagged colonies per 7 m radius plot (n=1 to 5 plots per site). A total of 192 colonies were originally tagged. Source: Williams and Miller, 2006.*

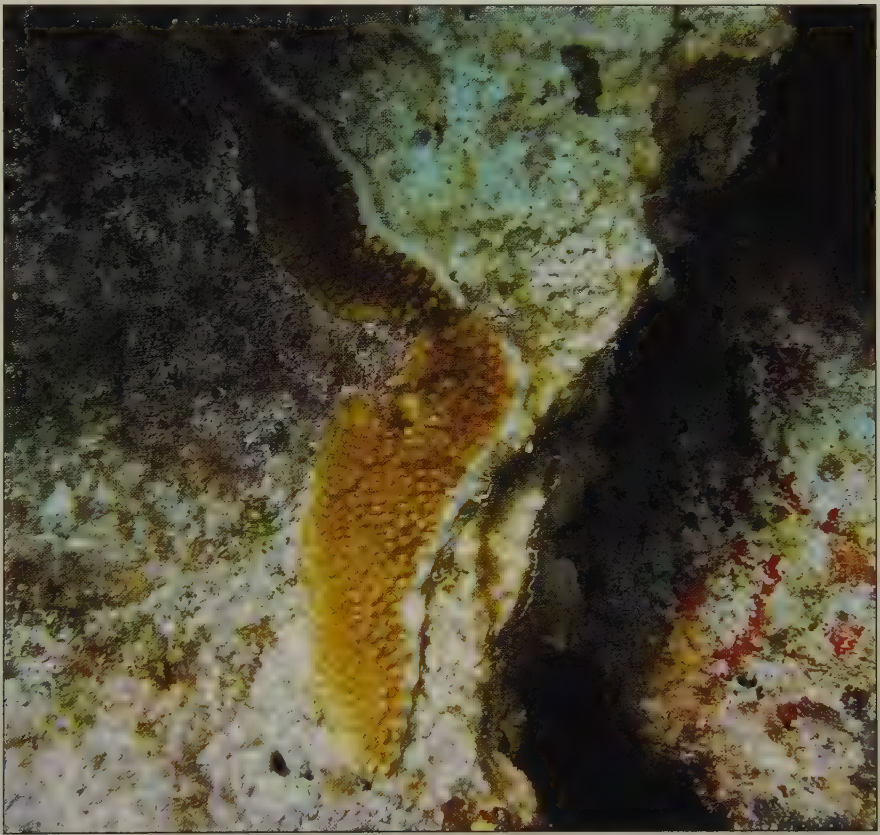


*Figure 6.20. Photograph of remnant crust approximately 20 cm long. After a series of hurricane impacts in summer/fall 2005, this was all that remained of a colony that was previously over a meter tall and wide. Photo: D. Williams.*

## ASSOCIATED BIOLOGICAL COMMUNITIES

Native Americans fished for reef fishes on Florida reefs long before the arrival of European settlers (Oppel and Meisel, 1871). Reef fishing accelerated in the 1920s. Following growing public conflicts and sharp declines in catches, monitoring programs at the species level began in the early 1980s (Bohnsack et al., 1994; Bohnsack and Ault, 1996; Harper et al., 2000, Ault et al., 2005a).

Recreational, commercial and "headboat" fisheries currently occur in Florida Keys waters. From a recreational standpoint, fishers include both local residents and visitors (FWC, 2007). Along the reef tract, the most commonly targeted species are members of the snapper-grouper complex, including snappers, groupers, grunts, hogfish and porgies. From a commercial standpoint, fisheries target reef and pelagic fish species, spiny lobster, stone crabs, blue crabs, shrimp and ballyhoo. Headboat fisheries, in which customers pay "by the head" to fish from vessels with a typical capacity of about 10-20 people, predominantly target reef species.

Trends in reef fish landings for the period 1981 to 1992 were reported for the Florida Keys by Bohnsack et al. (1994). Depending on the year, recreational landings comprised between 40 and 66% of total landings. Reef fishes accounted for 58% of total fish landings, 69% of recreational landings and 16% of commercial landings. Commercial landings were dominated by invertebrates (spiny lobster, shrimp and stone crabs), which comprised 63% of total landings.

In a 2005 report to the U.S. Congress, the National Marine Fisheries Service (NMFS) classified 11 species that are landed in the Florida Keys as overfished (i.e., depleted below minimum standards), and 11 as subject to overfishing (i.e., being fished at a rate that would lead to being overfished), with some overlap between the two categories (NMFS, 2005). Included in these totals are reef-associated species such as gag (*Mycteroperca microlepis*), black (*M. bonaci*), red (*Epinephelus morio*), snowy (*E. niveatus*), Warsaw (*E. nigritus*), Goliath (*E. itajara*) and Nassau (*E. striatus*) groupers, speckled hind (*E. drummondhayi*), and red (*Lutjanus campechanus*) and vermilion (*Rhomboplites aurorubens*) snappers. Fisheries for Goliath and Nassau groupers and for queen conch (*Strombus gigas*) were closed in 1985 and remain closed today, although the Goliath grouper stock continues to indicate signs of recovery (Porch et al., 2003 and 2006) to the extent that considerable debate occurs regarding re-opening of that fishery.

Ault et al. (1998) assessed the status of multiple reef fish stocks and determined that 13 of 16 groupers (Epinephinilae), seven of 13 snappers (Lutjanidae), one wrasse (hogfish; Labridae) and two of five grunts (Haemulidae) were overfished according to federal (NMFS) standards (Figure 6.21). They suggested that some stocks appeared to have been chronically overfished since the 1970s, and that the Florida Keys fishery exhibits classic "serial overfishing" in which the largest, most desirable species are depleted by fishing (Ault et al., 1998). Ault et al. (2001) found that the average size of adult black grouper in the upper Keys was about 40% of its 1940 value, and that the spawning stock for this species is now less than 5% of its historical unfished maximum. In subsequent analyses, Ault et al. (2005a and 2005b) determined that, of 34 species within the snapper-grouper complex for which sufficient data were available, 25 were experiencing overfishing.

Partly in response to concerns about fishing pressure, the FKNMS established a series of Sanctuary Preservation Areas (SPAs) in 1997. Comparison of fish and benthic communities within versus outside of SPAs is underway. The FKNMS also created the Tortugas Ecological Reserve (TER) in 2001 to protect coral reef ecosystem services in that area and support sustainable reef fisheries. The TER protects 150 nmi$^2$ and prohibits all anchoring, fishing and other extractive activities; it was the largest marine reserve in North America when first implemented. Scientists at the University of Miami and NMFS have studied and reported on responses of coral reef fish populations to this reserve. Based on data collected during more than 4,000 research dives, they compared changes in the Dry Tortugas region between 1999 and 2000 before the reserve was established and in 2004, three years after the reserve was established (Ault et al., 2006). As predicted by marine reserve theory, significant regional increases in abundance for several exploited and non-exploited species were detected. Significantly greater abundance of large fish were found in the TER for black grouper (Figure 6.22), red grouper (Figure 6.22) and mutton snapper compared to the baseline period. No significant declines were detected for any exploited species in the reserve, while non-exploited species showed both increases and declines. Abundance of exploited species in fished areas on the Tortugas Bank either declined or did not change. A comparison of black grouper size distributions as a function of management zone is given in Figure 6.23.

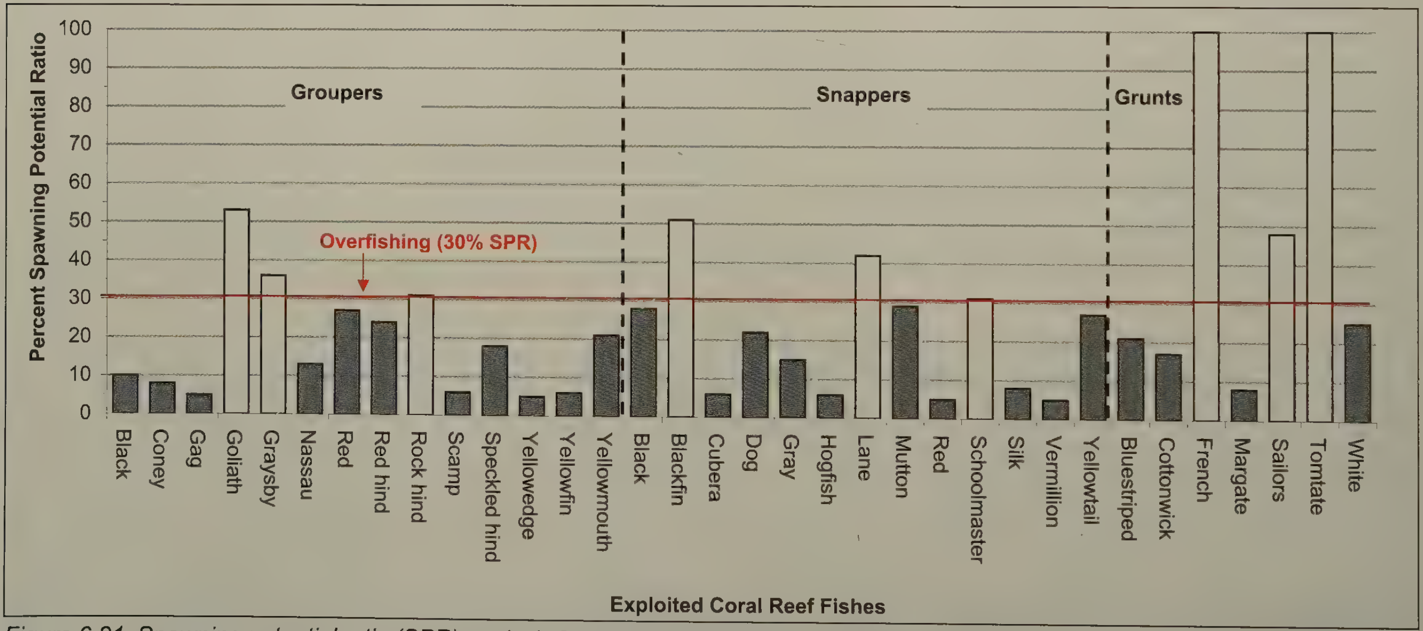


*Figure 6.21. Spawning potential ratio (SPR) analysis for 34 exploited species in the snapper-grouper complex from the Florida Keys for period 2000-2002. Dark bars indicate overfished stocks and open bars indicate stocks that are above the 30% SPR standard. Source: redrawn from Ault et al., 2005a.*

On January 19, 2007 the National Park Service (NPS) established a 119 km$^2$ (46 mi$^2$) Research Natural Area within the DTNP. This area is contiguous to the northern portion of the FKNMS Tortugas Ecological Reserve and effectively expanded the marine reserve network since it also prohibited all anchoring and extraction. Ongoing research and monitoring are planned to ascertain whether patterns observed in protected areas in the Tortugas are due to influences of marine reserves, confounding effects of recent changes in fishing regulations, hurricane disturbances, or random oceanographic and chance recruitment events.

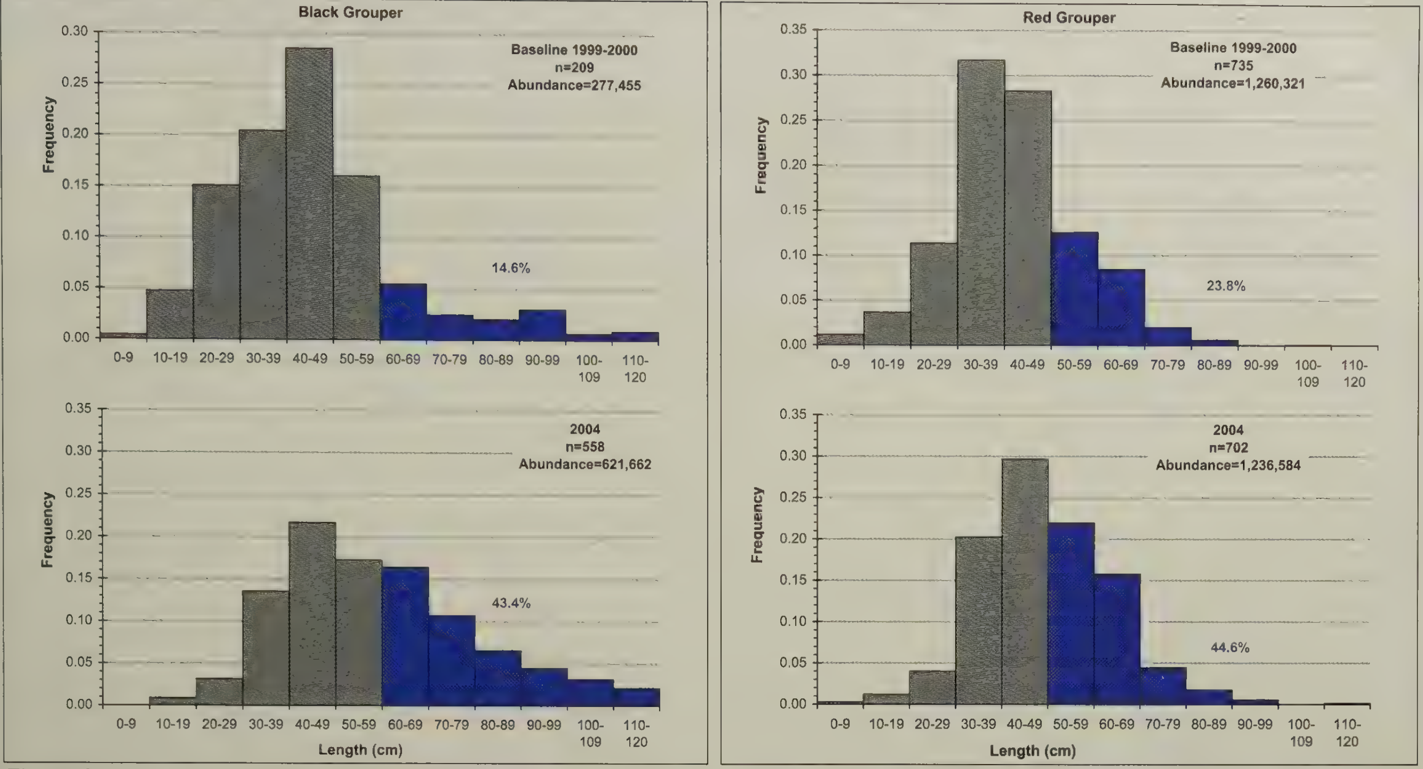


Figure 6.22. Black grouper (Mycteroperca bonaci; *left panels) and red grouper (*Epinephelus morio; *right panels) size distributions from the Tortugas region in 1999-2000 (top) and 2004 (bottom), before and after the establishment of the TER in 2001. Blue bars represent size classes larger than the minimum legal minimum size. Percentages show the proportion of the population larger than the legal minimum size of capture. Source: redrawn from Ault et al., 2006.*

## FWC Finfish Monitoring

Florida's Fish and Wildlife Conservation Commission (FWC) conducts visual censuses between April and October to monitor finfish populations along the Atlantic margin of the Florida Keys in waters of the FKNMS. The principal goal of the visual census surveys is to evaluate the relative abundance, size structure and habitat utilization of the reef fish species that comprise local, commercial and recreational fisheries in the Florida Keys reef ecosystem. The consistent application of monitoring methods and robust sample sizes permit meaningful statistical analysis of the data collected.

*Methods*

For the purposes of this study, the sampling universe in the FKNMS was divided into six geographical zones, designated A through F, four of which (A–D) were sampled during the present study (Figure 6.24). A habitat-based, random-stratified site selection procedure, based upon the *Benthic Habitats of the Florida Keys* GIS maps (NOAA, 1998), was used to select 39 sample sites (13 in Zone A, 10 in Zone B, 6 in Zone C and 10 in Zone D) each month. Sampling sites were randomly selected using a one longitudinal by one latitudinal minute grid (approximately 1 nmi$^2$) system. One mile square grids containing areas defined as "Patch Reefs" and "Platform Margin Reefs" were included in the sampling universe, with further random selection of one of 100 "micro-grids" within each selected sampling grid (Figure 6.24). Within each grid chosen for sampling, a second random selection of one of one hundred 0.1′ x 0.1′ "micro-grids" (approximately 0.01 nmi$^2$) determined the nominal location within the grid, providing that micro-grid contained reef or patch reef habitat adequate for sampling purposes (Figure 6.24). If this was not the case, a randomization procedure was used to relocate the sample to a nearby micro-grid with the desired habitat.

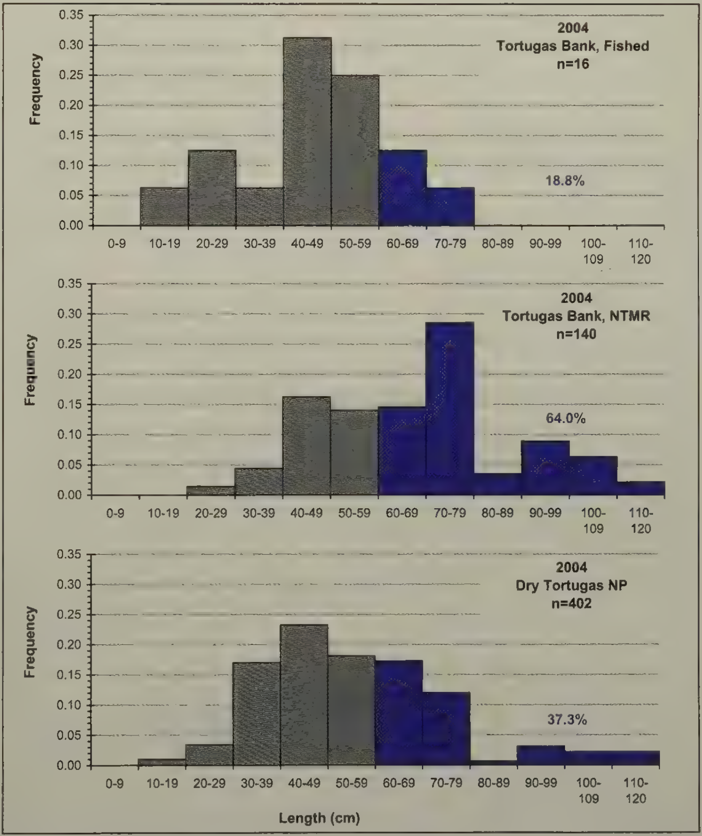


*Figure 6.23. Black grouper size distributions in 2004 from fished (top) areas on the Tortugas Bank, unfished (middle) areas in the NTMR and recreational angling areas in the DTNP (bottom). Blue bars indicate size classes larger than minimum legal size; percentages show the proportion of the population larger than legal minimum size. Source: redrawn from Ault et al., 2006.*

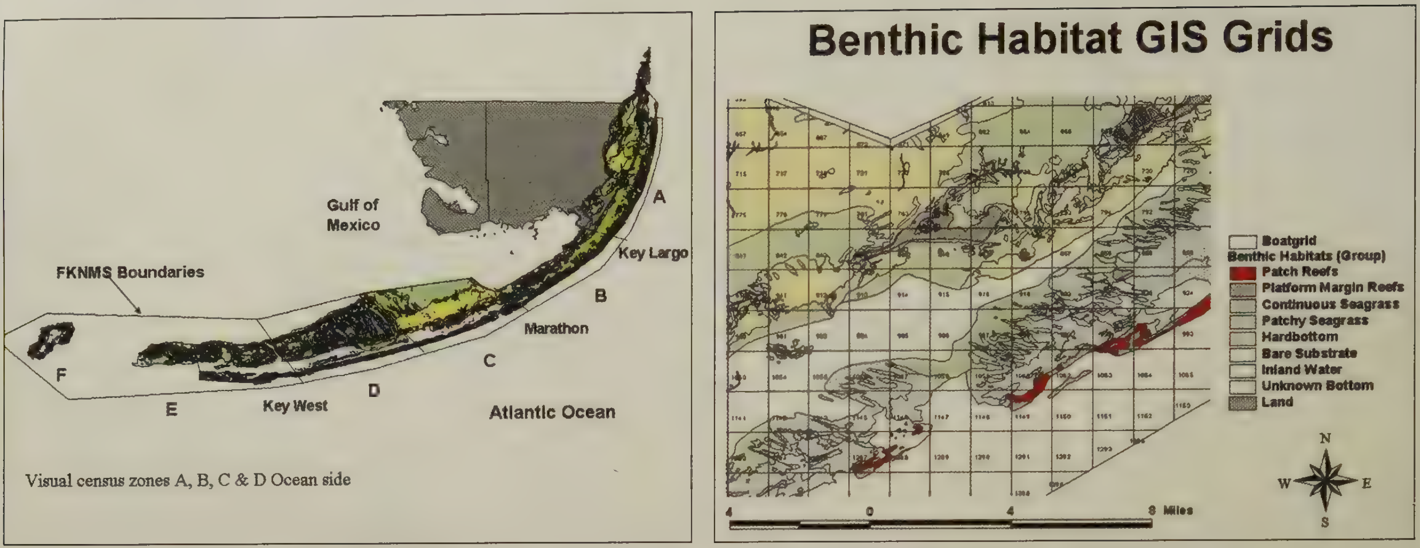


*Figure 6.24. Map of Fisheries-Independent Monitoring Program sampling areas divided into four zones (A-D), in the FKNMS (left), representing a habitat-based, random-stratified site selection procedure based upon FDEP and NOAA's (1998) mapping product "Benthic Habitats of the Florida Keys" (right). Source: FWC-FWRI, 2007; FDEP and NOAA, 1998.*

In 1999 and 2000, data was collected using both belt transects and point counts. From 2001-2007, only stationary visual point counts were used. In this method, a stationary diver records the number of individuals of each target species that are observed within an imaginary 5 m radius cylinder and assign length intervals to each. Two divers conduct a total of four point counts at each site. During the visual survey, each diver lays out a 25 m tape in a pre-determined direction opposite from the other diver. The tapes are laid as straight as possible within the same habitat type, with at least a 15 m distance between each point count. The first count is conducted at the 10 m mark, and a second count is conducted at 25 m. If suitable habitat is not present at the designated mark then the distance is adjusted accordingly. At each survey point, the diver stops and remains still for two minutes, allowing for a settling period. During this time period, the diver records depth, substrate, habitat type, relief, complexity, percent and type of biotic coverage within the area to be surveyed, which is the cylindrical area extending out 5 m from the center point and from the substrate to the surface. After the settling period, the diver records the time and begins estimating the number of fish in each five-centimeter size class for all the target species present. The diver has three minutes to allow the fish to naturally redistribute themselves and to list the target species present within the survey cylinder. This time period also allows for cryptic species to reveal themselves for counting. The target species include 54 species of commercial and recreational importance that are members of the following families: Haemulidae (13 species); Serranidae (13 species); Lutjanidae (nine species); Chaetodontidae (seven species); Balistidae (three species); Labridae (three species); Phomacanthidae (two species) and Priacanthidae (two species).

### *Results and Discussion*

Overall mean densities (number of fish/100 m$^2$) observed from point counts ranged from 37 fish/100 m$^2$ in 2000 to a high of 69 fish/100 m$^2$ in 2003. Overall mean densities have been increasing since 2001 (Figure 6.25) and were higher in Zone C and lower in zone D. A total of 273,191 animals of the target species were recorded during 6,454 point count surveys between 1999 and 2006 (Table 6.3). 89% of these fish were from the smallest size classes (>5 to 20-25 cm range). Fish in the family Haemulidae strongly dominated the point count observations, accounting for 67.6% of all individuals recorded, with *Haemulon plumieri*, *H. aurolineatum*, *H. sciurus* and *H. flavolineatum*, comprising 58.7% of the total number of haemulids (Table 6.3).

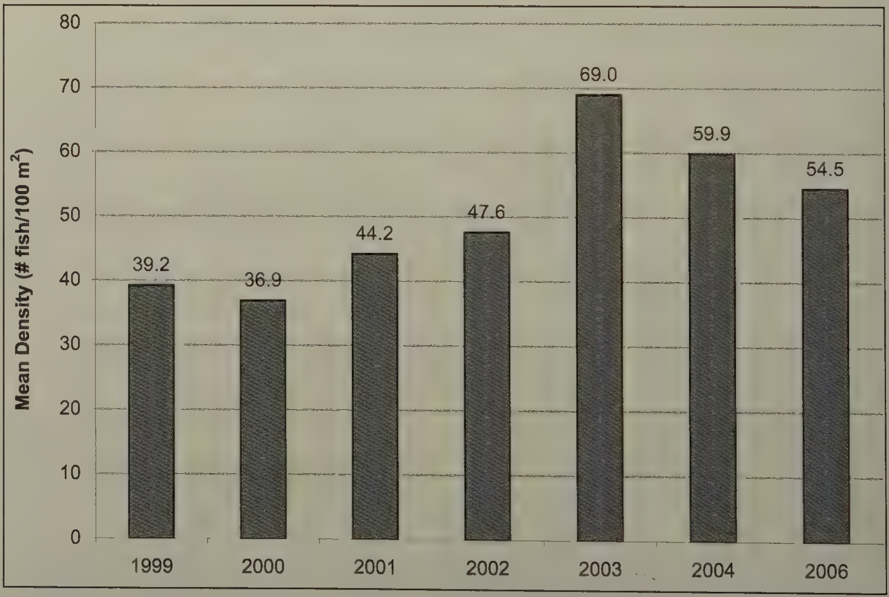


*Figure 6.25. Mean fish density by year (2000-2006) as recorded during visual surveys in the Florida Keys. Source: FWC-FWRI, 2007.*

Overall length-frequencies observed during point counts have been largely similar between years for most species. Length ranges and size distributions for economically important species such as *Ocyurus chrysurus*, *Lutjanus griseus*, *L. maximus*, *Epinephelus morio* and *Mycteroperca bonaci* have been very consistent through the years sampled. Only a small percentage of groupers and snappers were observed in the larger size classes during the seven years of sampling, and these percentages varied by species and year. For example, observations of large individuals of *E. morio* decreased from 22.8% in 2004 to 16.8% in 2006; sightings of large *M. bonaci*, increased from 15.0% in 2004 to 16.4% in 2006. No legal-size (i.e., fish that can legally be caught and retained) individuals of *M. microlepis* were observed in 2006, compared to 11.1% in 2004. *Ocyurus chrysurus* showed a slight increase in the number of legal-size fish observed with 4.8% at or above the legal limit in 2006 compared to 3.8% in 2004, yet this was still lower than in 2003 (7.4%).

*Table 6.3. Catch statistics for the 15 more abundant Reef Fish Species observed during Florida Keys visual sampling, 1999-2006. Percent (%) is the percentage of the total observations represented by that species; percent occurrence (% Occur) is the percentage of samples in which the species was observed; CV is the coefficient of variation. Taxa are ranked in order of decreasing mean density. Source: FWC-FWRI, 2007.*

| SPECIES | NUMBER | | % OCCUR | DENSITY ESTIMATE (ANIMALS/100 m$^2$) | | | |
|---|---|---|---|---|---|---|---|
| | No. | % | | Mean | SE | CV | Max |
| *Haemulon plumieri* | 57,017 | 20.9 | 82.4 | 11.50 | 0.55 | 193.82 | 342.82 |
| *Haemulon aurolineatum* | 52,227 | 19.1 | 20.3 | 10.17 | 1.16 | 461.30 | 925.01 |
| *Ocyurus chrysurus* | 26,162 | 9.6 | 65.9 | 5.75 | 0.32 | 224.87 | 154.49 |
| *Haemulon sciurus* | 28,017 | 10.3 | 41.5 | 5.71 | 0.44 | 309.10 | 291.57 |
| *Haemulon flavolineatum* | 22,879 | 8.4 | 41.0 | 4.57 | 0.35 | 310.47 | 226.00 |
| *Haemulon spp.* | 16,815 | 6.2 | 10.1 | 3.38 | 0.48 | 576.75 | 318.31 |
| *Lutjanus griseus* | 13,241 | 4.8 | 35.5 | 2.95 | 0.29 | 403.80 | 268.23 |
| *Lachnolaimus maximus* | 7,400 | 2.7 | 79.3 | 1.62 | 0.07 | 167.30 | 45.41 |
| *Lutjanus apodus* | 5,441 | 2.0 | 19.1 | 1.21 | 0.16 | 547.55 | 143.88 |
| *Anisotremus virginicus* | 4,697 | 1.7 | 47.2 | 0.96 | 0.07 | 285.19 | 56.34 |
| *Pomacanthus arcuatus* | 3,490 | 1.3 | 67.2 | 0.75 | 0.03 | 146.03 | 13.58 |
| *Chaetodon capistratus* | 3,455 | 1.3 | 52.3 | 0.74 | 0.03 | 145.13 | 7.64 |
| *Haemulon melanurum* | 3,693 | 1.4 | 8.5 | 0.72 | 0.13 | 714.10 | 93.90 |
| *Haemulon chrysargyreum* | 3,502 | 1.3 | 4.9 | 0.70 | 0.14 | 788.99 | 95.49 |
| *Pomacanthus arcuatus* | 3,490 | 1.3 | 67.2 | 0.75 | 0.03 | 146.03 | 13.58 |
| *Chaetodon capistratus* | 3,455 | 1.3 | 52.3 | 0.74 | 0.03 | 145.13 | 7.64 |
| **Subtotal** | 197,964 | 72.7 | -- | -- | -- | -- | -- |
| **Totals** | 273,191 | 100.0 | -- | 56.03 | 1.99 | 143.90 | 1,141.77 |

## MACROINVERTEBRATES

### *FWC Spiny Lobster Monitoring*

The FWC undertook a lobster monitoring program in 1997 to test the hypothesis that no-take zones would sufficiently protect spiny lobster so that their average abundance and size would increase in protected zones compared to similar fished areas. Spiny lobster monitoring in the FKNMS began at the time of reserve establishment.

*Methods*

From 1997-2001, 13 reserves and similar adjacent fished areas were surveyed during the closed and open fishing seasons. Reserves were comprised of 11 SPAs (mean size 82 ha), one large SPA (515 ha) and one 3,000 ha Ecological Reserve (ER) at Western Sambo. From 2002 through 2005, sampling effort at three sites including the ER was only conducted during the closed fishing season. A full survey of the 13 reserve/fished area pairs was conducted during the closed season of 2006, the tenth year of the reserves. Surveys consisted of 60-minute timed searches for spiny lobsters. More information on data collection methods can be found in Cox and Hunt (2005).

*Results and Discussion:*

In 1997, mean lobster size was below the legal limit in both reserves and exploited areas. Since protection, mean lobster size in reserves has been larger than legal size, whereas in exploited areas it remained below the legal limit in most years. In all years, legal-sized lobsters with a carapace length ≥76 mm found in SPAs were as large as or larger than those in fished areas (Figure 6.26). In most years, abundance declined in both reserves and exploited areas during the open season, but the decline was less precipitous in reserves. The decline in lobster abundance inside reserves during the fishing season indicates that the reserves are too small to adequately protect lobsters from harvest.

In Western Sambo ER, the mean size of legal lobsters and the frequency of occurrence of very large lobsters, especially males, increased steadily after protection was implemented in 1997. The overall abundance of spiny lobsters in the reserve varied without trend among years, but the abundance of legal-sized lobsters during the closed season increased significantly in the reserve relative to the exploited area (Cox and Hunt, 2005). It is apparent that some lobsters remain in this larger reserve for a long period of time, and it appears that a residential population of spiny lobsters is becoming established within the reserve. Western Sambo ER is an effective fishery reserve for spiny lobsters, presumably because of its larger size and protected status.

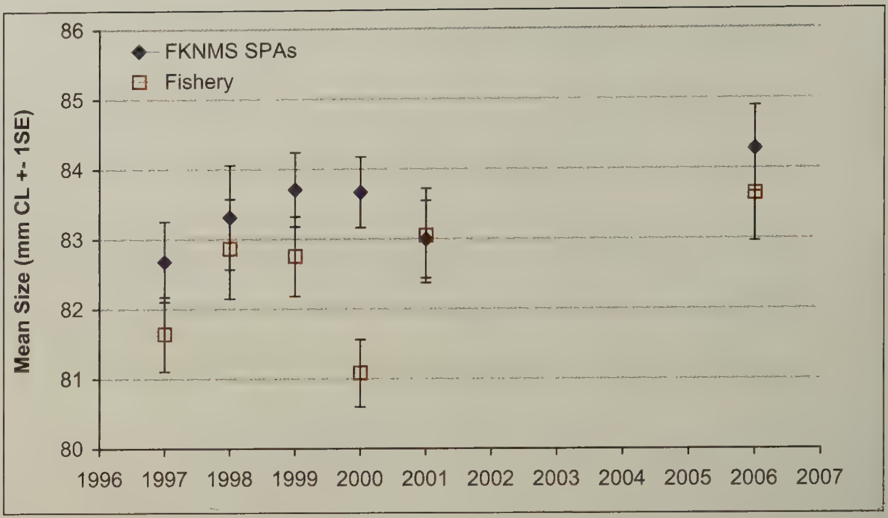


*Figure 6.26. Size of legal (≥76 mm carapace length) lobsters in FKNMS SPAs (blue) and similar fished areas (red) during the closed fishing season (July). Source: Cox and Hunt, 2007.*

## *FWC Queen Conch Monitoring in the Florida Keys*

### *Methods*

The FWC monitors the recovery of the queen conch (*Strombas gigas*) population in the Florida Keys by conducting belt-transects in locations with known conch aggregations, including marine reserves and adjacent reference areas. All conch within a 2 m belt-transect (laid out across an aggregation) were counted and mapped. Density and area estimates were used to determine population abundance. More information on data collection methods can be found in Glazer and Delgado (2003).

### *Results and Discussion*

Since Florida's queen conch fishery was closed in 1986, there have been signs that adult queen conch have begun to recover (Glazer and Delgado, 2003; Figure 6.27). By 2003, adult conch density had increased to about 700 conch/ha yielding approximately 37,000 adults within breeding aggregations. However, this trend was reversed in 2004 and 2005 as density and overall abundance declined in both years. Since most of the breeding aggregations are in relatively shallow water (<5 m), the active hurricane seasons during these two years may have negatively impacted the aggregations. There was a slight rebound in density and overall abundance in 2006 to about 600 conch per ha and 25,500 adults.

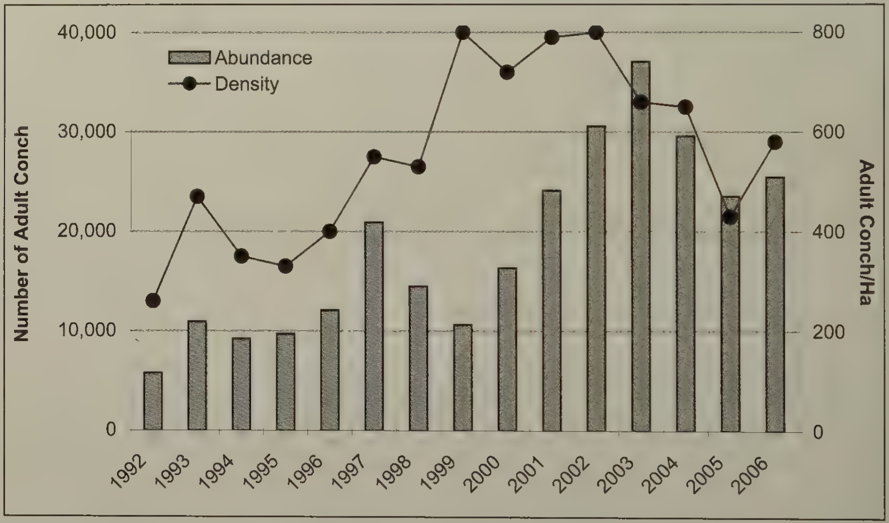


*Figure 6.27. Trends in the density and abundance of adult queen conch (*Strombus gigas*) in the Florida Keys, estimated from yearly monitoring of the breeding aggregations on the back reef. Source: Glazer and Delgado, 2003.*

## CURRENT CONSERVATION MANAGEMENT ACTIVITIES

### Mapping

In 2000, NOAA and the Fish and Wildlife Research Institute (FWRI) released habitat maps for the Florida Keys (Figure 6.28), representing the first large-scale effort to map coral ecosystem habitats in the Florida reef tract from Biscayne Bay to the Dry Tortugas. Habitats were delineated based on visual interpretation of 1991-1992 aerial photographs.

Shallow-water coral reef ecosystems of southern Florida encompass an estimated 30,800 km$^2$ and extend from the Dry Tortugas in the Florida Keys as far north as St. Lucie Inlet on the Atlantic Ocean coast and Tarpon Springs on the Gulf of Mexico coast (Rohmann et al., 2005). The collaborative Southern Florida Shallow-water Coral Ecosystem Mapping Implementation Plan (MIP), released in June 2005, discusses the need to produce shallow-water (about 0-40 m depth) benthic habitat and bathymetric maps of approximately 13,000 km$^2$ of critical areas in southern Florida (Figure 6.29). The plan was developed using extensive input from over 90 representatives of state regulatory and management agencies, federal agencies, universities and non-governmental organizations involved in the conservation and management of Florida's coral reef ecosystems. The MIP can be obtained at http://ccma.nos.noaa.gov/ecosystems/coralreef/fl_mapping.html.

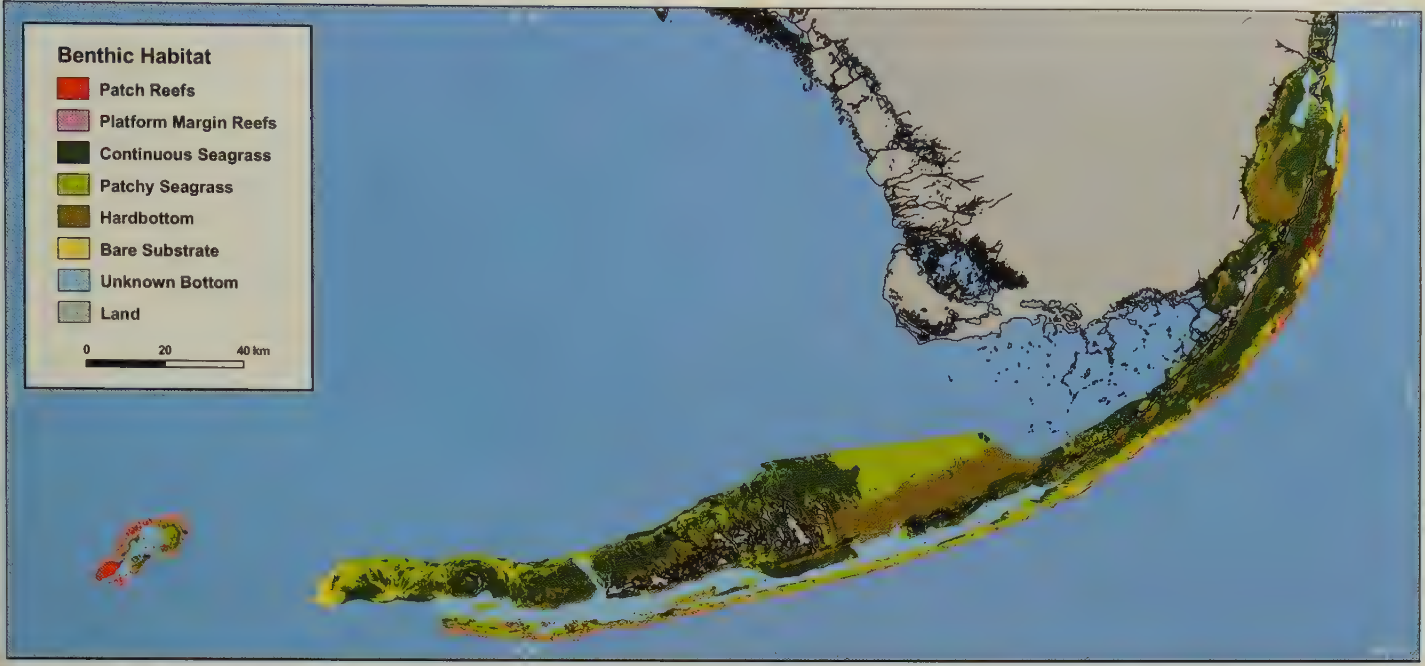


*Figure 6.28. Nearshore habitat maps were developed by CCMA-BB based on visual interpretation of aerial photography and hyperspectral imagery. The maps were released in 2000. For additional information, visit: http://biogeo.nos.noaa.gov. Map: K. Buja.*

Since 2004, NOAA's Center for Coastal Monitoring and Assessment, Biogeography Branch (CCMA-BB) has worked with state, university, and other federal partners to share the costs of gathering imagery and field data, manage contracts and other activities related to mapping coral reef ecosystems of southern Florida. Since 2005, CCMA-BB has purchased nearly 10,000 km$^2$ of color, high-resolution, commercial satellite imagery that will be used for delineating benthic habitats. Figure 6.30 shows satellite imagery available as a georeferenced mosaic for essentially 100% of the Florida Keys. While efforts were made to collect during optimal environmental conditions, the seafloor is not always visible in imagery as a result of widespread turbidity and some clouds. Several more years may be required to obtain suitable imagery of the entire area. NOAA has co-registered the color and panchromatic satellite imagery to Florida's 2004 Digital Orthophoto Quadrangles and is making it available through the NOS Data Explorer (http://oceanservice.noaa.gov/dataexplorer/whatsnew/welcome.html).

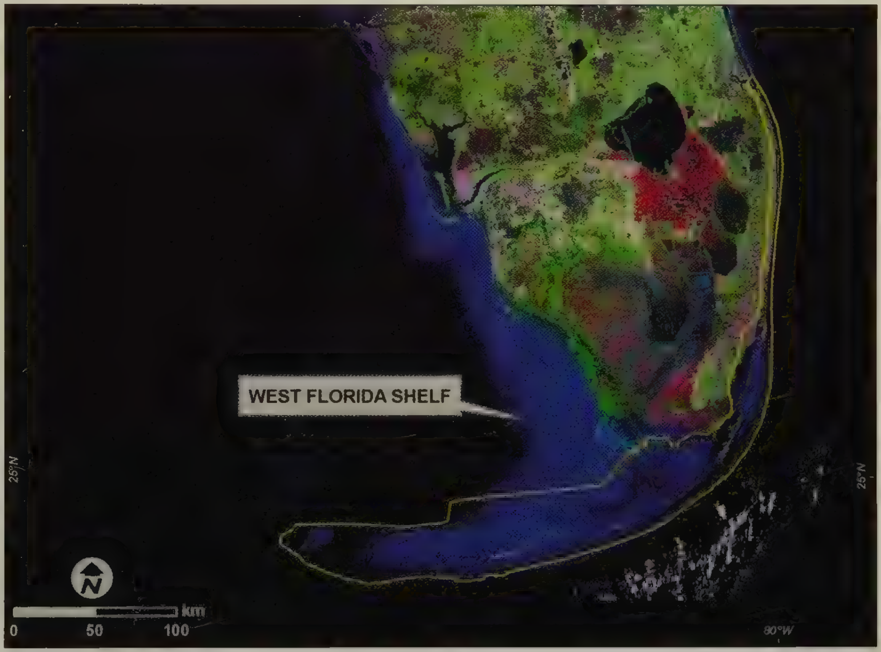


*Figure 6.29. The yellow polygon delineates the approximately 13,000 km$^2$ priority shallow-water benthic habitat mapping area of southern Florida. Source: S. Rohmann, unpub. data.*

Starting in 2007, NOS began producing maps of benthic habitats in the Hawk Channel portion of the Florida Keys. As of June 2008, draft maps have been completed for approximately 530 km$^2$ of Hawk Channel. A three-year grant from the Florida Wildlife Legacy Initiative to NOS will be used to map an additional estimated 975 km$^2$ of Hawk Channel. In the fall of 2008, NOS will begin mapping a further 335 km$^2$ of Hawk Channel. A benthic habitat map is considered draft until an independent accuracy assessment and peer review is completed. The NOS intends to work with NOVA Southeastern University's National Coral Reef Institute to conduct the accuracy assessment.

In April 2008, Florida's FWC plans to complete draft habitat maps of a portion of Biscayne Bay and the Dry Tortugas. This mapping activity, conducted in partnership with the NPS, will focus on the patch reefs found in these areas. High-resolution aerial photography, acquired in 2005, will provide the base imagery for the Biscayne Bay characterization. The satellite imagery discussed above will be used for the Dry Tortugas characterization.

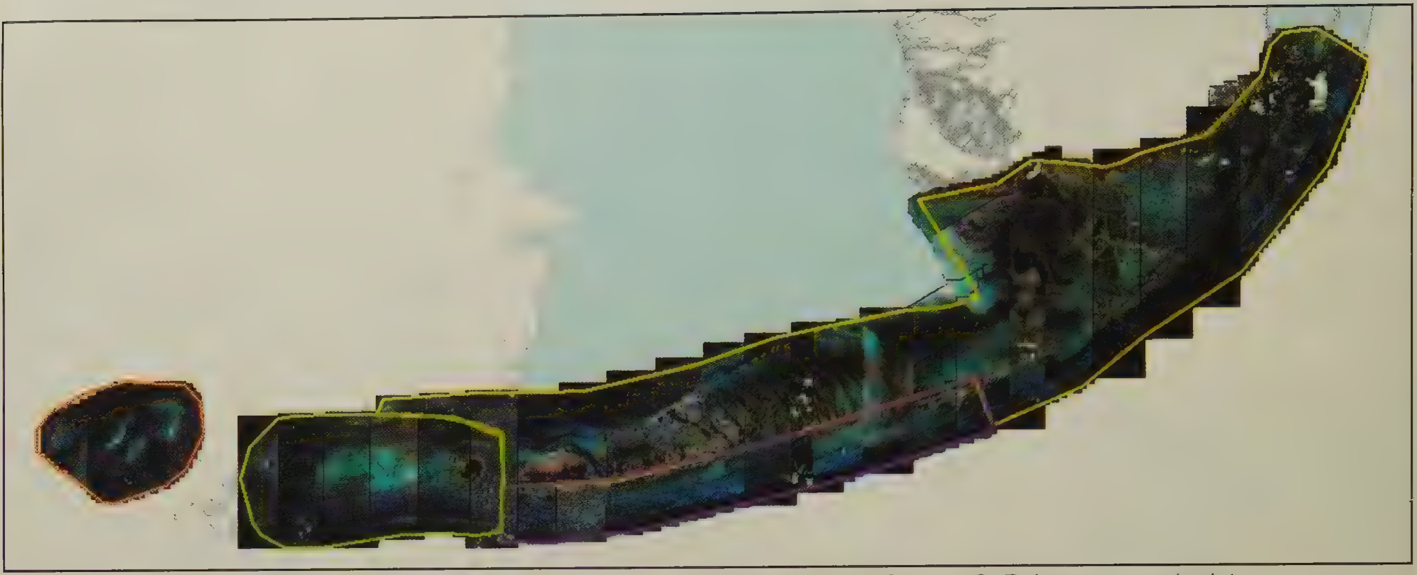


*Figure 6.30. Satellite imagery collections of southern Florida as of November 2006. Source: S. Rohmann, unpub. data.*

In April 2007, the NOS deployed a 25 ft boat equipped with an interferometric acoustic sonar system to collect bathymetry and associated side scan sonar imagery of the Hawk Channel in the Western Sambos Ecological Reserve southeast of Key West. Because it is not affected by turbidity, the interferometric sensor was able to collect data of the area despite poor water clarity conditions. NOS hopes to use these data to classify the more turbid portions of the Western Sambos.

### Assessments, Monitoring and Research

Assessments, monitoring and research are conducted in the Florida Keys by many groups, including local, state and federal agencies, public and private universities, private research foundations, environmental organizations and independent researchers. Sanctuary staff facilitates and coordinates research by registering researchers through a permitting system, recruiting institutions for priority research activities, overseeing data management, and disseminating findings to the scientific community and the public.

The Water Quality Protection Program, which began in 1994 and is funded by U.S. Environmental Protection Agency, the USACE and NOAA gathers data on water quality, seagrasses, and coral reef and hard-bottom communities (Keller and Donahue, 2006). Information about these projects is provided throughout this report and at the following Web sites: http://ocean.floridamarine.org/fknms_wqpp/, http://serc.fiu.edu/wqmnetwork/FKNMS-CD/index.htm, http://www.fiu.edu/~seagrass/ and http://www.floridamarine.org/features/category_sub.asp?id=2360.

The Marine Zone Monitoring Program monitors a system of 24 marine reserves located within the FKNMS. Implemented in 1997, the goal of the program is to determine whether these fully protected zones effectively protect marine biodiversity and enhance human uses related to the sanctuary. Parameters measured include the abundance and size of fish and invertebrates, as well as economic and human dimensions of the sanctuary and compliance with regulations. This program monitors changes in ecosystem structure (size and number of invertebrates, fish, corals and other organisms) and function (coral recruitment, herbivory, predation). Human uses of zoned areas are also tracked. A summary report on findings of this monitoring program and other elements of the science program of the FKNMS is available online (Keller and Donahue, 2006; see also Cox and Hunt, 2005; and Ault et al., 2006).

### MPAs and Fully Protected Areas

A significant addition to fully protected areas in the Florida Keys came with the authorization of the General Management Plan of the DTNP in January 2007, which includes a no-take Research Natural Area covering 158 km$^2$ (nearly half) of the DTNP. A monitoring plan for the Park including its newly revised zoning plan is being developed by NPS and FWRI staff.

### Gaps in Monitoring and Conservation Capacity

A significant need in the Florida Keys is a complete, updated and high-resolution benthic habitat map as described in the mapping section above.

### Coral Spawning Partnership 2007

An inaugural coral spawning research cruise was conducted in August of 2006, with the goals of initiating conservation-based coral research, continuing to educate scientists and students, and establishing an initial baseline of knowledge of coral spawning at Looe Key's Management Area, which has been federally protected since 1981. The cruise was operated by FKNMS and Florida's Department of Environmental Protection (FDEP) and supported 12 scientists and four students from various agencies including FDEP, EPA, NMFS, FWC, Mote Marine Laboratory, the University of Florida, the University of Texas at Austin, the FWRI and the World Wildlife Fund. Spawning observations of major reef building species are listed in Table 6.4. Participating scientists also took advantage of this event to initiate studies on coral reproduction, settlement and aquaculture of threatened coral species in the Florida Keys.

*Table 6.4. The 2006 spawning observation timeline for reef building corals at Looe Key, Florida, USA. Source: Ritchie, unpub. data.*

| CORAL SPECIES | DAY 2* | DAY 3 | DAY 4 | DAY 5 | DAY 6 | DAY 7 | DAY 8 | DAY 9 |
|---|---|---|---|---|---|---|---|---|
| *Acropora palmata* | — | Pre-spawn | Full spawn 10:25 pm-11:15 pm | Intermed spawn 10:35 pm-11:15 pm | — | — | — | — |
| *Acropora cervicornis* | Post-spawn | — | — | — | — | — | — | — |
| *Montastrea annularis* | — | — | — | — | — | 11:45 pm | 11:25 pm-11:45 pm | — |
| *Montastrea faveolata* | — | — | — | — | — | 9:55pm-12 am | Heavy spawn 11:11 pm-12:15 am | 11:45 pm-12 am |
| *Montastrea cavernosa* | — | — | — | — | Pre-spawn | 8:00 pm-10:00 pm | Post spawn | — |
| *Diploria strigosa* | — | — | — | — | — | 10:35 pm-10:45 pm | 8:30 pm-12:20 pm | Post spawn |
| *Dendrogyra cylindricus* | — | — | Male spawn 9:50 pm | — | — | — | — | — |

*Days after the first full moon in August or 2006 (August 8th).

## OVERALL CONCLUSIONS AND RECOMMENDATIONS

A large amount of coral cover has been lost in the Florida Keys over the past 12 years. Monitoring programs have shown an overall decline in hard coral cover of 44% at quantitatively surveyed stations. Proportionally, the major framework building corals seem to have been most affected (73% loss for *Acropora palmata*, and 37% loss for *Montastraea annularis*). Many of the causes of local coral decline originate beyond the jurisdiction of local resource managers. For example, algal blooms in the Florida Keys are influenced by nutrients and water flows from the Everglades and southwest Florida coast. Also, warming ocean temperatures associated with global climate change are a major factor in coral bleaching. Implementing solutions that will preserve the Florida Keys coral reef system will require action on regional and global scales.

The Florida Keys is host to several environmental monitoring programs and research projects that provide information useful for the development of protective policies and management strategies. Resource managers must actively work to collect information from these multiple sources, and also incorporate observations from local residents, to get a more complete picture of coral reef and related habitats.

Some of the most promising research may be in the areas of coral physiology, reproduction and genetics. These studies will provide information that helps predict responses to environmental conditions, identify etiology of coral diseases and increase the success of reef restoration projects.

The coral reef is a vital component of the tourism and fisheries-based economies of the Florida Keys, where millions of people congregate annually to enjoy the region's recreational experiences and seafood harvest. Continued protection of this important coral reef ecosystem will benefit from broad-based stewardship and greater public awareness and support.

## REFERENCES

Andrews, K., N. Nall, C. Jeffrey, and S. Pittman. 2005. The State of Coral Reef Ecosystems of the Main Hawaiian Islands. pp. 222-269. In: J.E. Waddell (ed.). The State of Coral Reef Ecosystems of the United States and Pacific Freely Associated States: 2005. NOAA Technical Memorandum NOS NCCOS 11. Silver Spring, MD. 522 pp.

Aronson, R.B. and W.F. Precht. 2001. Applied paleoecology and the crisis on Caribbean coral reefs. Palaios 16: 195-196.

Ault, J.S., J.A. Bohnsack, and G. Meester. 1998. A retrospective (1979-1995) multispecies assessment of coral reef fish stocks in the Florida Keys. Fish. Bull. 96(3): 395-414.

Ault, J.S., S.G. Smith, G.A. Meester, J. Luo, and J.A. Bohnsack. 2001. Site Characterization for Biscayne National Park: Assessment of Fisheries Resources and Habitats. NOAA Technical Memorandum NMFS SEFSC 468. Miami, FL. 185 pp.

Ault, J.S., S.G. Smith, and J.A. Bohnsack. 2005a. Evaluation of average length as an indicator of exploitation status for the Florida coral-reef fish community. ICES J. Mar. Sci. 62: 417-423.

Ault, J.S., J.A. Bohnsack, S.G. Smith, and J. Luo. 2005b. Towards sustainable multispecies fisheries in the Florida, USA, coral reef ecosystem. Bull. Mar. Sci. 76(2): 595-622.

Ault, J.S., S.G. Smith, J.A. Bohnsack, J. Luo, D.E. Harper, and D.B. McClellan. 2006. Building sustainable fisheries in Florida's coral reef ecosystem: positive signs in the Dry Tortugas. Bull. Mar. Sci. 78(3): 633-654.

Bohnsack, J.A., D.E. Harper, and D.B. McClellan. 1994. Fisheries trends from Monroe County, Florida. Bull. Mar. Sci. 54: 982-1018.

Boyer, J.N. and H.O. Briceño. 2006. FY2005 Annual Report of the Water Quality Monitoring Project for the Florida Keys National Marine Sanctuary. Southeast Environmental Research Center Technical Report T-327. Florida International University. Miami, FL. 91 pp. http://serc.fiu.edu/wqmnetwork/Report%20Archive/2005FKNMS.pdf.

Boyer, J.N. and H.O. Briceño. 2007. FY2006 Annual Report of the Water Quality Monitoring Project for the Florida Keys National Marine Sanctuary. Southeast Environmental Research Center Technical Report T-354. Florida International University. Miami, FL. 77 pp. http://serc.fiu.edu/wqmnetwork/Report%20Archive/2006FKNMS.pdf.

Clark, C. 2006. Lobster fishermen stake it all on 2006 season. Miami Herald. Miami, FL. http://www.redorbit.com/news/business/605221/lobster_fishermen_stake_it_all_on_2006_season/index.html.

Cox, C. and J.H. Hunt. 2005. Change in size and abundance of Caribbean spiny lobsters *Panulirus argus*, in a marine reserve in the Florida Keys National Marine Sanctuary, USA. Mar. Ecol. Prog. Ser. 294: 227-239.

Cox, C. and J.H. Hunt. 2007. Caribbean spiny lobsters in Florida Keys National Marine Sanctuary Reserves - 10 years later. Abstract. p.141. In: 8th International Conference and Workshop on Lobster Biology and Management, Programme and Abstracts. Prince Edward Island, Canada. 158 pp.

Davis, G.E. 1977. Anchor damage to a coral reef on the coast of Florida. Biol. Conserv. 11(1): 29-34.

Davis, G.E. 1982. A century of natural change in coral distribution at the Dry Tortugas: A comparison of reef maps from 1881 and 1976. Bull. Mar. Sci. 32: 608–623.

Florida Department of Environmental Protection and National Oceanic and Atmospheric Administration (FDEP and NOAA). 1998. Benthic habitats of the Florida Keys. FMRI Technical Report TR-4. Florida Marine Research Institute. St. Petersburg, FL. 53 pp.

Florida Fish and Wildlife Conservation Commission (FWC). 2007. Fishing Capital of the World. http://fishingcapital.com/.

Frank, K.T., B. Petrie, J.S. Choi, and W.C. Leggett. 2005. Trophic cascades in a formerly cod-dominated ecosystem. Science 308(5728): 1621-1623.

Gardner, T.A., I.M. Côté, J.A. Gill, A. Grant, and A.R. Watkinson. 2003. Long-term region-wide declines in Caribbean corals. Science 301(958): 958-960

Garrett, G. Monroe County Division of Marine Resources. Marathon, FL. Personal communication.

Glazer, R.A and G.A. Delgado. 2003. Towards a holistic strategy to managing Florida's queen conch (*Strombus gigas*) population. pp. 73-80. In: D. Aldana Aranda (ed.). El Caracol Strombus gigas: Conocimiento Integral para su Manejo Sustentable en el Caribe. CYTED, Programa Iberoamericano de Ciencia y Technología para el Desarrollo. Yucatán, México. 165 pp.

Harper, D.E., J.A. Bohnsack, and B. Lockwood. 2000. Recreational Fisheries in Biscayne National Park, Florida, 1976-1991. Mar. Fish. Rev. 62: 8-26.

Johns, G.M., V.R. Leeworthy, F.W. Bell, and M.A. Bonn. 2001. Socioeconomic Study of Reefs in Southeast Florida, Final Report. Technical Report 01-10. Broward County Environmental Protection Department. FL. 348 pp. http://www.broward.org/environment/bri01714.pdf.

Johns, G.M., J.W. Milon, and D. Sayers. 2004. Socioeconomic Study of Reefs in Martin County, Florida. Final Report. Martin County, FL. 120 pp. http://marineeconomics.noaa.gov/Reefs/MartinCounty2004.pdf.

Keller, B.D. and S. Donahue (eds.). 2006. 2002-03 Florida Keys National Marine Sanctuary science report: an ecosystem report card after five years of marine zoning. Marine Sanctuaries Conservation Series NMSP 06-12. NOAA National Marine Sanctuary Program. Silver Spring, MD. 358 pp. http://sanctuaries.noaa.gov/science/conservation/fk_report.html.

Kimball, M.E., J.M. Miller, P.E. Whitfield, and J.A. Hare. 2004. Thermal tolerance and potential distribution of invasive lionfish (*Pterois volitans*/miles/complex) on the east coast of the United States. Mar. Ecol. Prog. Ser. 283: 269-278.

Leeworthy, V.R., T. Maher, and E.A. Stone. 2006. Can Artificial Reefs Alter User Pressure on Adjacent Natural Reefs? Bull. Mar. Sci. 78(1): 29-37.

Mace, P. 1997. Developing and sustaining world fishery resources: state of science and management. pp. 1-20. In: D.A. Hancock, D.C. Smith, A. Grant, and J.P. Beumer (eds.). Proceedings of the Second World Fishery Congress. Brisbane, Australia. 797 pp.

McClenachan, L. 2008. Social conflict, overfishing and disease in the Florida sponge fishery. pp. 1849-1939. In: D. Starkey (ed.). Oceans Past: Management Insights from the History of Marine Animal Populations. Earthscan Publications Limited, London. 250 pp.

Miller, M.W. (compiler). 2002. Acropora corals in Florida: Status, trends, conservation, and prospects for recovery. pp. 59-70 In: A.W. Bruckner (ed.). Proceedings of the Caribbean Acropora workshop: potential application of the U.S. Endangered Species Act as a conservation strategy. NOAA Technical Memorandum NMFS OPR 24. Silver Spring, MD.

Miller, S.L., M. Chiappone, L.M. Rutten, D.W. Swanson, and R. Waara. 2006a. Surveys of benthic coral reef organisms in Dry Tortugas Park and the Tortugas Bank, western Florida Keys National Marine Sanctuary. Quick Look Report: Tortugas Region Cruise. Center for Marine Science. University of North Carolina at Wilmington. Wilmington, NC. 10 pp. http://people.uncw.edu/millers/CoralReef_QuickLooks.htm.

Miller, S.L., M. Chiappone, L.M. Rutten, and D.W. Swanson. 2006b. Population assessment of staghorn (*Acropora cervicornis*) and elkhorn corals (*A. palmata*) in the upper Keys region of the Florida Keys National Marine Sanctuary. 2006 Quick Look Report: Acropora. Center for Marine Science. University of North Carolina at Wilmington, NC. 7 pp. http://people.uncw.edu/millers/CoralReef_QuickLooks.htm.

National Marine Fisheries Service (NMFS). 2005. Status of Fisheries of the United States - Report to Congress. http://www.nmfs.noaa.gov/sfa/statusoffisheries/SOSmain.htm.

National Marine Fisheries Service (NMFS). 2007. Marine Recreational Fisheries Statistics Survey (MRFSS). Fisheries Statistics Division, NOAA NMFS Office of Science and Technology. Silver Spring, MD. http://www.st.nmfs.noaa.gov/st1/index.html.

National Oceanic and Atmospheric Administration (NOAA). 1998. Benthic Habitats of the Florida Keys digital data product. Special Projects Office. Silver Spring, MD. ftp://spo.nos.noaa.gov/datasets/benthic_habitats.

Oppel, F. and T. Meisel. 1871. Along the Florida Reef. pp. 265-309. In: Tales of Old Florida. Castle Press. Seacaucus, NJ. 480 pp.

Porch, C.E., A.M. Eklund, and G.P. Scott. 2003. An assessment of rebuilding times for goliath grouper. SEDAR6-RW-3. Sustainable Fisheries Division, NMFS Southeast Fisheries Science Center. Miami, FL. 25 pp. http://www.sefsc.noaa.gov/sedar/.

Porch, C.E., A.M. Eklund, and G.P. Scott. 2006. A catch-free stock assessment model with application to goliath grouper (*Epinephelus itajara*) off southern Florida. Fish. Bull. 104: 89-106.

Reef Environmental Education Foundation. 2006. Online database. http://www.reef.org/programs/exotic.

Rohmann, S.O., J.J. Hayes, R.C. Newhall, M.E. Monaco, and R.W. Grigg. 2005. The area of potential shallow-water tropical and subtropical coral ecosystems in the United States. Coral Reefs 24(3): 370-383.

Semmens, B.X., E.R. Buhle, A.K. Salomon, and C.V. Pattengill-Semmens. 2004. Tankers or fish tanks: what brought non-native marine fishes to Florida waters. Mar. Ecol. Prog. Ser. 266: 239-244.

Sheridan, P., R. Hill, G. Matthews, R. Appeldoorn, B. Kojis, and T. Matthews. 2005. Does trap fishing impact coral reef ecosystems? An update. pp. 511-519. In: Proceedings of the 56th Gulf and Caribbean Fisheries Institute. Tortola, British Virgin Islands. 851 pp.

Waddell, J.E. (ed.). 2005. The state of coral reef ecosystems of the United States and Pacific Freely Associated States: 2005. NOAA Technical Memorandum NOS NCCOS 11. Silver Spring, MD. 522 pp.

Wilkinson, C.R. 1996. Global change and coral reefs: Impacts on reefs, economies and human cultures. Global Change Biol. 2(6): 547-558.

Williams, D.E., M.W. Miller, and K.L. Kramer. 2006. Demographic monitoring protocols for threatened Caribbean *Acropora* spp. corals. NOAA Technical Memorandum NMFS SEFSC 543. Miami, FL. 91 pp.

# The State of Coral Reef Ecosystems of the Flower Garden Banks, Stetson Bank, and Other Banks in the Northwestern Gulf of Mexico

Emma L. Hickerson[1], G.P. Schmahl[1], Martha Robbart[2], William F. Precht[3] and Chris Caldow[4]

## INTRODUCTION AND SETTING

The East and West Flower Garden Banks (EFGB and WFGB) were designated as the Flower Garden Banks National Marine Sanctuary (FGBNMS) through the National Oceanic and Atmospheric Administration (NOAA) in January 1992. The two banks are prominent geological features located near the outer edge of the continental shelf in the northwestern Gulf of Mexico, approximately 192 km southeast of Galveston, Texas (Figure 7.1). These features, created by the uplift of underlying salt domes of Jurassic origin, rise from surrounding water depths of over 100 m to within 17 m of the surface. The northernmost thriving coral reef communities in North America cap the shallow portions of the EFGB and WFGB. They are relatively isolated from other coral reefs of the Caribbean and Gulf of Mexico, located over 690 km from the nearest reefs of the Campeche Bank off Mexico's Yucatan Peninsula, and over 1,200 km from the coral reefs of the Florida Keys. The area of the EFGB (27°54.5' N, 93°36.0' W) comprises about 65.8 km$^2$ of which about 1.02 km$^2$ is coral reef. Located 19.3 km to the west, the WFGB (27°52.5' N, 93°49.0' W) comprises about 77.2 km$^2$ of which about 0.4 km$^2$ is coral reef (Gardner et al., 1998).

Structurally, the shallowest component of the Flower Garden Banks' (FGB) coral community is comprised of aggregations of large, closely spaced boulder and brain coral heads that grow to up to 3 m or more in diameter and height (Figure 7.2). Reef topography is relatively rugose, with many vertical and inclined surfaces. Between groups of coral heads, there are numerous sand patches and channels. Coral growth is relatively uniform over the entire top of both banks, occupying the bank crests down to about 50 m. As the reef slopes downward on the flanks of the bank tops, coral growth occurs in a more plate-like fashion to maximize exposure to available sunlight, and individual heads can cover large areas. Despite the low species numbers on the reef crest, the reefs exhibit extremely high coral cover, ranging on average between 45-52% down to 30 m depth, and up to 70% in areas down to at least 43 m depth.

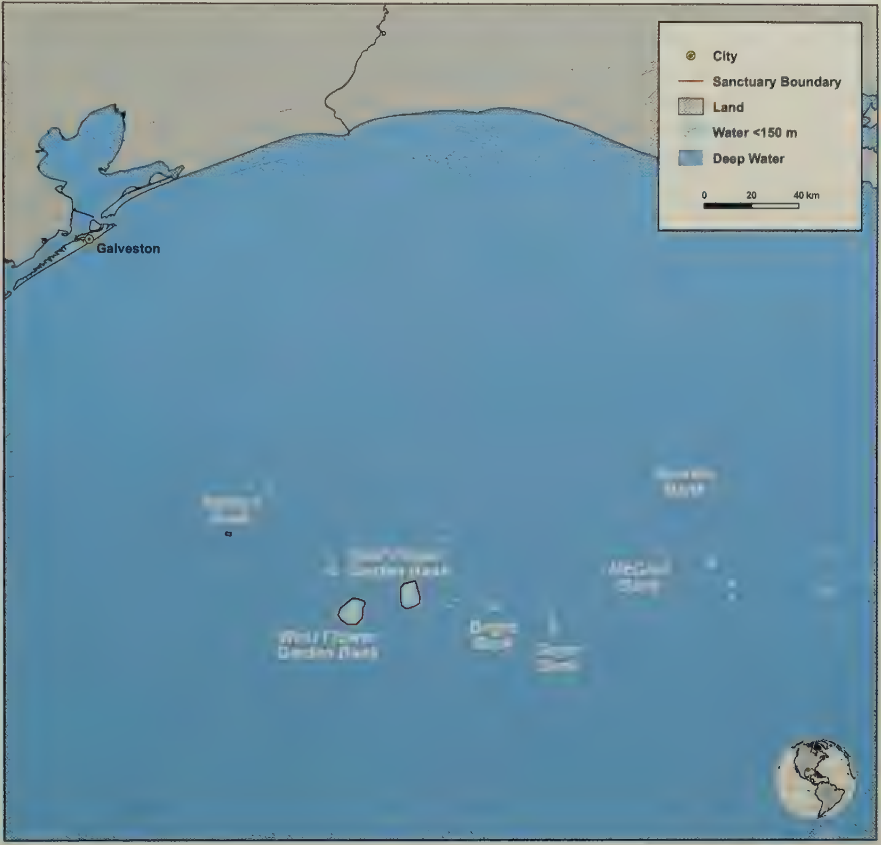


Figure 7.1. Map showing the locations of banks in the northwestern Gulf of Mexico. Map: K. Buja.

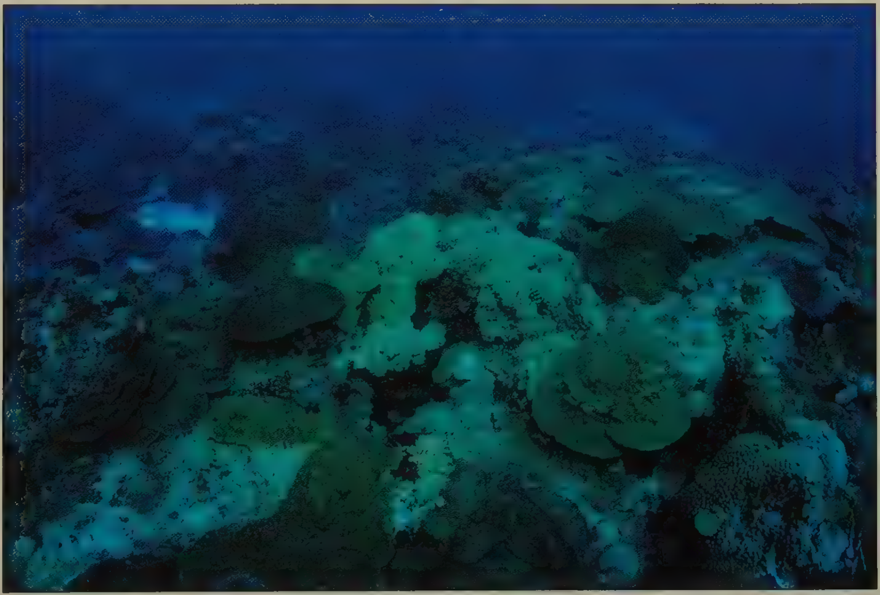


Figure 7.2. Boulder and brain corals are typically found on the coral caps of the FGB. Photo: G.P. Schmahl.

---

[1] NOAA Flower Garden Banks National Marine Sanctuary
[2] PBS&J
[3] NOAA Florida Keys National Marine Sanctuary
[4] NOAA National Ocean Service, Center for Costal Monitoring and Assessment, Biogeography Branch

There is a relatively low diversity (only about 21 species) of reef-building corals on the FGB likely due to its geographic isolation, annual range of water temperature and other factors. Interestingly, the coral reefs of the FFGB contain practically no elkhorn (*Acropora palmata*) or staghorn corals (*A. cervicornis*) and none of the shallow-water sea whips or sea fans (gorgonians) that are common elsewhere in the Caribbean. Deepwater surveys below 43 m, however, reveal a rich diversity of gorgonians and antipatharian corals.

Stetson Bank was added to the FGBNMS in 1996. It is located 48 km to the northwest of the WFGB and is also associated with an underlying salt dome. Stetson Bank is classified as a mid-shelf bank (Rezak et al., 1985) and is comprised of claystone/siltstone outcrops forming distinct pinnacles near its northern edge. Stetson Bank is not a true coral reef, but it does contain a low diversity coral community in addition to a prominent sponge fauna. Stetson Bank is dominated by fire coral (*Millepora alcicornis*) and in certain areas ten-ray star coral (*Madracis decactis*). These two species collectively make up about 32% of coral cover in the pinnacle region (Bernhardt, 2000). Stetson Bank is composed of claystone outcroppings that have been pushed within 17 m of the sea surface. Including the two dominant species, about 10 species of coral have been documented. The pinnacle region is the most conspicuous feature of the bank, which stretches along the northwest face of Stetson Bank for approximately 500 m. With the addition of Stetson Bank, the FGBNMS encompasses 145.8 km$^2$ and includes the entire bank areas of each of the three features.

In addition to the coral reefs within the FGBNMS, there are a number of other reefs and banks in the northwestern Gulf of Mexico that contain corals or coral communities. The FGB and Stetson Bank are part of a network of over one hundred continental shelf-edge features off the coasts of Texas and Louisiana. Many of these topographic features were the subjects of baseline scientific investigations in the late 1970s and early 1980s (Rezak et al., 1985). These studies first documented that a number of the banks contained coral reef resources. Additional surveys by FGBNMS staff and collaborators have provided further insight into the nature of these banks, of which at least four harbor substantial populations of scleractinian coral. They are: Bright Bank (11 species; Rezak et al., 1985; FGBNMS observations), Sonnier Bank (nine species; Rezak et al., 1985; Weaver et al., 2006), Geyer Bank (four species; Rezak et al., 1985, FGBNMS observations) and McGrail Bank (nine species; Rezak et al., 1985; Weaver et al., 2006; FGBNMS observations). The coral communities at McGrail Bank are of special interest. Recent surveys have revealed a community dominated by the blushing star coral (*Stephanocoenia intersepta*) which covers up to 30% of the seafloor in some areas at depths between 45 and 60 m (Schmahl and Hickerson, 2006; Figure 7.3).

*Figure 7.3. McGrail Bank contains colonies of the blushing star coral (*Stephanocoenia intersepta*). Photo: FGBNMS/NURC-UNCW.*

High resolution multibeam bathymetry of the reefs and banks and surrounding deepwater areas around the FGB has revealed structural connectivity previously not reported. This structural connectivity provides the basis for biological and ecological connectivity of many of the reefs and banks in the NW Gulf of Mexico, creating "habitat highways" which may support greater movement of species and individuals between locations. Recent manta ray (*Manta birostris*) tagging studies at the FGBNMS have verified multiple bank use by individual manta rays (R. Graham, pers. comm.), strengthening the connectivity concept in this region.

Many of the other banks in the northwestern Gulf of Mexico contain extensive communities of a variety of deeper water coral assemblages, characterized by antipatharians, gorgonians, solitary corals and species of branching corals such as *Oculina* spp. and *Madrepora* spp. These types of communities are typically observed in depths from 60 m to 150 m, and exhibit similar populations at similar depths and habitat types across the reefs and banks along the shelf edge. All of the reefs and banks in the vicinity provide hardbottom substrate that has been colonized by a high diversity of benthic invertebrates and serves as important habitat for a wide range of reef fish species (Dennis and Bright, 1988). These banks are currently unprotected, with the exception of regulation of direct impacts from oil and gas development. Further investigations are warranted to fully determine the extent of these living marine resources.

The FGBNMS sustained a number of disturbances in 2005, many of which are reported in more detail in this chapter. The first widespread FGBNMS coral disease event on record occurred during the early months of the year. This was followed by two major hurricanes passing through the region later in the season, one of which resulted in an enormous plume of discolored water originating from the Texas and Louisiana coast, moving rapidly out and over the FGBNMS. During this same time period, the onset of the most severe Caribbean coral bleaching event on record occurred.

In 2006, the FGBNMS created a Sanctuary Advisory Council and initiated a Management Plan Review (MPR), which is currently in progress. As with other Sanctuary MPR processes, a series of ongoing public scoping meetings provided an opportunity for user groups, such as recreational SCUBA divers, recreational and commercial fishers, and the oil and gas industry, to help identify issues of importance. The results of the meetings and additional input from regional experts provided guidance for development of working groups charged with addressing specific topics. Issues under scrutiny include fishing, visitor use, boundary expansion, pollutant discharge, enforcement and education.

## ENVIRONMENTAL AND ANTHROPOGENIC STRESSORS

### Climate Change and Coral Bleaching

It has long been suggested that the location and depth of coral reefs at Gulf of Mexico banks buffer them from the most acute short-term effects of global warming and climate change. Prior to 2005, the prevalence of coral bleaching was relatively low (less than 4% annually; Hagman and Gittings, 1992; Gittings et al., 1993; U.S. DOI-MMS, 1996; Dokken et al., 1999, 2003; Precht et al., 2008a). In 2005, elevated water temperatures were present on the reef cap for 50 days until September 23, 2005. By late August 2005, a bleaching event was underway at the FGBNMS. By October 2005, after the passage of two major hurricanes in the Gulf of Mexico, FGBNMS surveys reported that as much as 46% of the individual colonies exhibited some level of bleaching. Surveys conducted by FGBNMS in March 2006 showed that approximately 4-5% of the coral colonies still exhibited varying degrees of bleaching. More detailed information and data describing coral bleaching in the FGB can be found in the Benthic Habitats portion of this chapter.

### Diseases

The incidence of disease has historically been very low at the EFGB and WFGB of the FGBNMS; however, in February 2005, the first widespread coral disease event was observed at both banks. This event affected multiple colonies and at least seven reef-building species. This plague-like disease, termed "white syndrome" (WS), has subsequently been surveyed and observed in 2006 and 2007. This disease (Figure 7.4) is more active during the winter months, which is quite different from typical plague-like coral diseases in the Caribbean. In 2007, 12-15% of the reef building corals were affected by the disease, and during winter surveys in 2007, partial mortality of affected corals at varying levels was recorded for the first time at the FGBNMS (A. Bruckner, pers. comm.) With the assistance of the Coral Disease and Health Consortium, a team of experts has been investigating the disease, including Andy Bruckner (NOAA Fisheries), Bob Jonas and Geoff Cooke (George Mason University). White band disease, which is common elsewhere in the tropical western Atlantic, has not been observed at the FGBNMS to date.

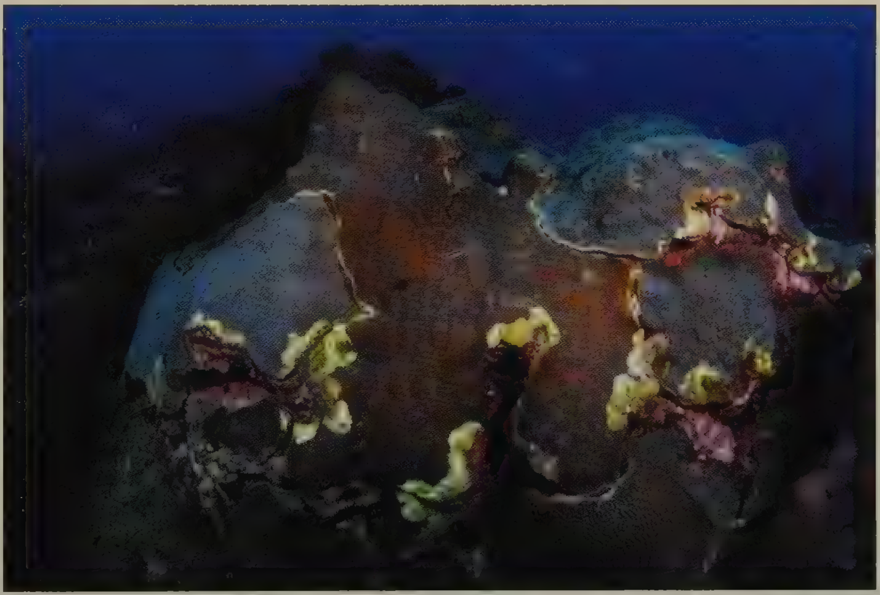


*Figure 7.4. Winter plague-like coral disease at the FGBNMS. Photo: FGBNMS/ Schmahl.*

### Tropical Storms

Since 2000, four hurricanes have passed near the FGB (Figure 7.5). In August 2005, Hurricane Katrina (not shown on map), one of the most destructive storms in U.S. history, made landfall a few hundred miles northeast of the FGBNMS, near New Orleans, LA. Soon thereafter, on September 23, 2005, Hurricane Rita, a Category 3 storm (Saffir-Simpson Index), passed within 50 miles of the FGB before making landfall on the Texas coast. Although staff were not able to visit the FGBNMS between the hurricanes, staff members did assess damage at the banks soon after the passage of Hurricane Rita and reported significant damage to the reef including large (3–4 m diameter) dislodged coral heads (Figure 7.6), gouged and damaged corals from waterborne projectiles (Figure 7.6), displacement of sand and sediment, removal of and injury to large barrel sponges (Figure 7.6) and scouring in sand channels (Figure 7.7). The expansive *Madracis mirabilis* field on the east side of the EFGB also experienced catastrophic levels of breakage and toppling (Figure 7.7).

On November 13, 2005, a team from PBS&J, was assembled to conduct further hurricane impact surveys, focusing on the 100 x 100 m monitoring site at the EFGB. Approximately 1.5% of the coral colonies photographed at the EFGB quadrat stations in August 2005 were missing, apparently as a result of the hurricane (Precht et al., 2008b). At Stetson Bank, scouring of the claystone/siltstone valleys occurred.

Researchers working at the EFGB Brine Seep, reported impacts to experiment stations at 72 m – the deepest documented impact of the storms within the FGBNMS (K. Parsons-Hubbard, pers. comm.).

Water temperature at the EFGB increased slightly as Hurricane Katrina moved towards New Orleans, while the passage of Hurricane Rita resulted in a drop in water temperature. Salinity decreased at both EFGB and Stetson Bank during the passage of Hurricanes Katrina and Rita. More detail on temperature and salinity fluctuations during storms can be found in the the Water Quality section of this chapter.

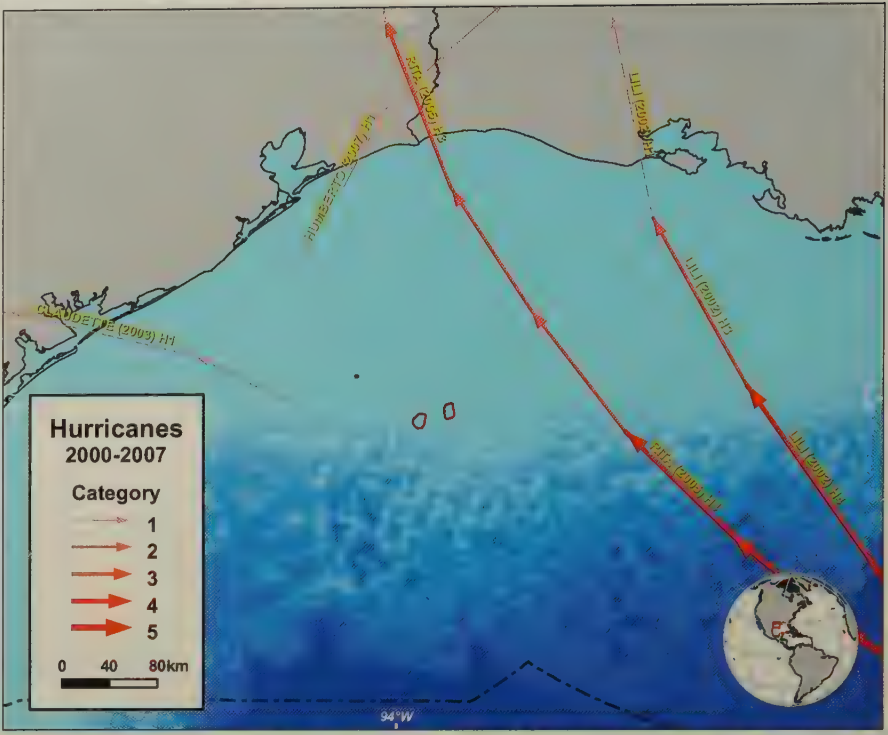


*Figure 7.5. A map showing the paths and intensities of hurricanes passing near the FGBNMS, 2000-2007. Map. K. Buja. Source: http://maps.csc.noaa.gov/hurricanes/.*

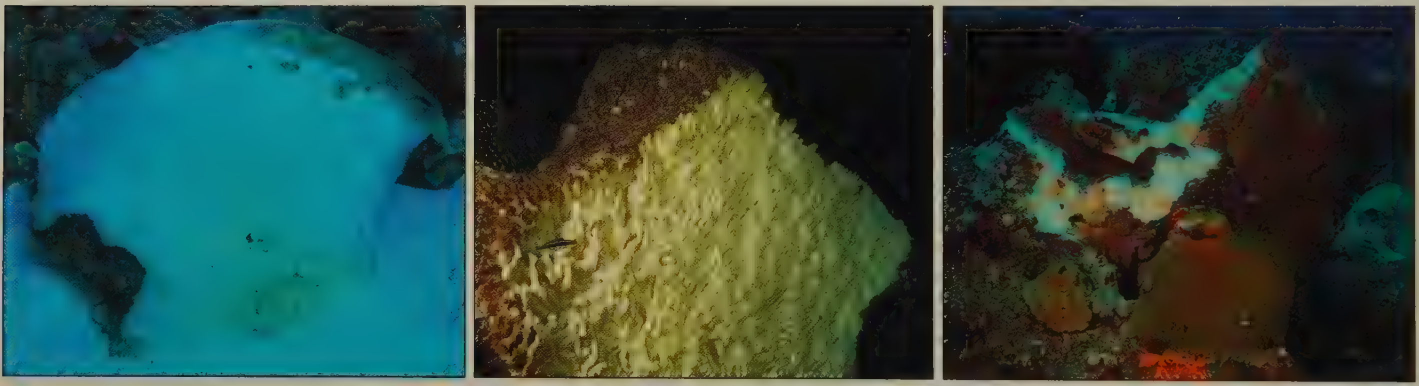


*Figure 7.6. From left to right: a large* Colpophyllia natans *colony was dislodged from the reef and tossed into a sand patch (left); another* Colpophyllia natans *sheared off during a storm (center); and storm damage to a barrel sponge (right). Left photo: FGBNMS/Hickerson; center and right photos: Joyce and Frank Burek.*

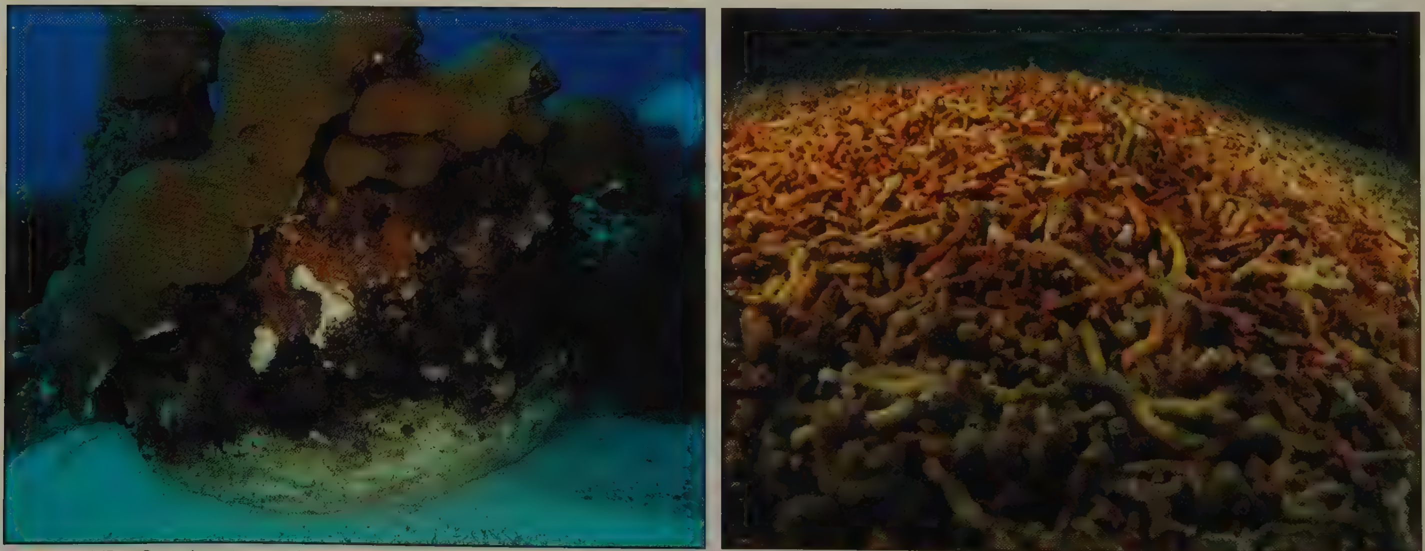


*Figure 7.7. Coral outcropping showing souring of sand channel (left). Photo: Joyce and Frank Burek. Yellow pencil coral,* Madracis mirabilis, *flattened during Hurricane Rita (right). Photo: TPWD/John Embesi.*

On September 12, 2007, Tropical Storm Humberto, the fastest developing storm on record, passed very near the FGBNMS before making landfall as a Category 1 hurricane on the Texas coast. The storm interrupted a monitoring cruise underway at the FGBNMS, forcing the scientists to abandon their mission and the ship to return to port. The effects, if any, from Hurricane Humberto on the FGBNMS will be included in the next report in this series.

## Coastal Development and Runoff

The primary sources of degraded water quality include coastal runoff, river discharges and effluent discharges from offshore activities such as oil and gas development and marine transportation (Deslarzes, 1998). Oxygen-depleted (hypoxic) near-bottom waters have been found in a large area of the northern Gulf of Mexico. Often called the "dead zone" this area has included up to 16,500 km$^2$ of the continental shelf from the Mississippi Delta to the Texas coast. Although relatively far from the FGB, there is concern that this area could continue to grow and impact outer continental shelf areas.

General coastal runoff and degraded nearshore water quality can potentially impact the banks through cross-shelf transport processes which bring turbid, nutrient-rich water offshore. Deslarzes (2007) postulates the fluorescent bands observed in the carbonate skeletons of some corals come from the seasonal transport of nearshore water onto the FGBNMS, which may be tainted by urban, agricultural and biological contaminants.

Research using nitrogen isotopes suggests a pathway for direct primary nitrogen input from coastal river sources from a considerable distance. While nitrogen isotopes from the FGB have signatures of oceanic origin (K. Dunton, pers. comm.), benthic algae from Stetson Bank have a distinct nitrogen isotope signature similar to plants found in coastal estuarine systems. These findings suggest that recent coastal influences are reaching only as far as Stetson Bank.

## Coastal Pollution

Hurricane Rita made landfall on the Texas-Louisiana border on September 24, 2005. The impact from the resultant rain and winds created a massive plume of discolored water originating from shore, and moving directly south. The plume reached the surface waters of the FGB by September 25 (Figure 7.8). Unfortunately the composition of this discolored water was not determined, and it is unknown at this time whether the water mass reached the coral caps. The discolored water persisted for at least one month after the hurricane event (NASA/GSFC; MODIS/NOAA CoastWatch; FGBNMS).

## Tourism and Recreation

Recreational scuba diving is a popular activity at the FGB, and demand appears to be increasing. There are currently two live-aboard charter dive vessels that regularly visit the banks (Figure 7.9). The M/V *Spree* carries up to 24 divers, and the M/V *Fling* can carry up to 35 divers. A third vessel with a carrying capacity of 30-40 divers has indicated that they plan to offer dive charters to the FGBNMS in the near future. In 1997, a survey of charter dive operations revealed that an estimated 2,350 divers visited the FGB. These divers spent $870,000 in Texas, of which approximately $636,000 was spent in the local economy of Freeport, where it generated $1.1 million in sales/output, $477,000 in income, and 24 full-time and part-time jobs. An additional $234,000 was spent in other areas of Texas, with $559,000 in sales/output, $228,000 in income, and 11 jobs (Ditton and Thailing, 2001).

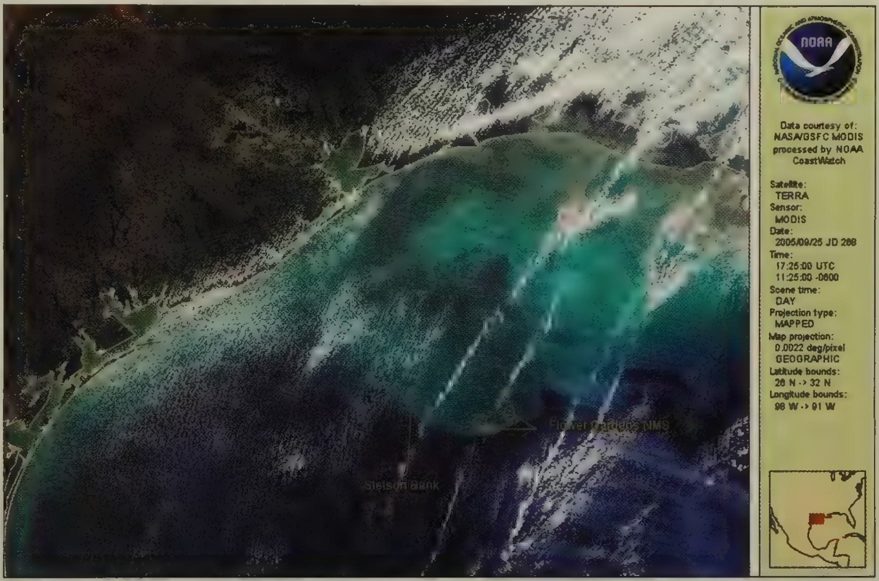


*Figure 7.8. Satellite imagery showing plume of discolored water immediately after Hurricane Rita. Source: NASA/GSFC; MODIS/NOAA CoastWatch.*

*Figure 7.9. The M/V* Spree*, one of two recreational dive charter vessels currently operating at the FGB, ties up to one of the FGBNMS' 17 mooring buoys. Photo: R. Wilkins.*

## Fishing

The impacts of fishing and associated activities are not well known. At this time, only traditional hook and line fishing is allowed in the FGBNMS. However, illegal fishing by both commercial long-liners and recreational spearfishers have been reported. Targeted fishing efforts, which are allowed under current regulations, could have a significant detrimental impact on snapper, mackerel and grouper populations. Anecdotal reports suggest that spawning aggregations are impacted from direct fishing pressure.

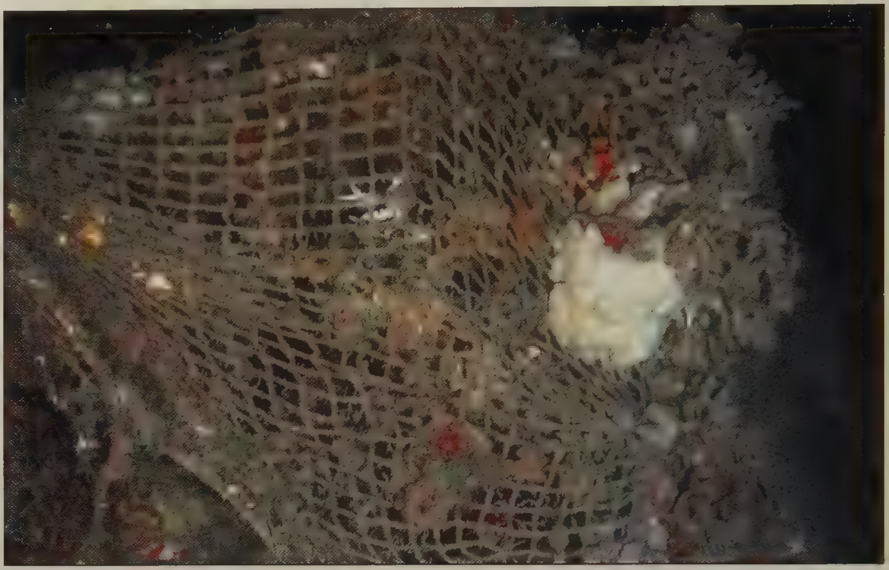


*Figure 7.10. Discarded shrimp net in deep water habitat at Stetson Bank. Photo: FGBNMS/ National Undersea Research Center-Univ. North Carolina, Wilmington.*

Lost and discarded fishing gear has been observed in the FGBNMS (Figure 7.10). Such objects can cause localized physical injury to coral reefs and have been known to entangle and injure sea turtles and other organisms. Illegally discarded fishing and shrimping bycatch has been reported by scuba divers.

Stetson Bank's proximity to the coast suggests greater use by recreational fishers than in other areas of FGBNMS. Due to the relatively soft nature of the substrate, Stetson Bank may be more prone to mechanical injury from fishing, which likely renders it more susceptible to disturbance from tropical storm and hurricane events. Evidence for this process comes from surveys conducted at Sonnier Bank, another mid-shelf bank similar in substrate and communities to Stetson Bank. Frequent visitors to Sonnier Bank have reported chronic incidents of anchor and fishing impacts. Post-Hurricane Rita surveys conducted by MMS, PBS&J and FGBNMS, revealed catastrophic impacts to the substrate there.

## Trade in Coral and Live Reef Species

This activity is prohibited by Sanctuary regulations.

## Ships, Boats and Groundings

Groundings do not occur at the FGBNMS due to the depth of the banks. However, anchors from large ships can have devastating local impacts to the living coral reef. Over the last 20 years there have been a number of incidences of significant impacts caused by the anchoring of large industry vessels, freighters and fishing vessels (Gittings et al., 1992). Foreign-flagged cargo vessels have occasionally anchored at the FGB without knowing of the anchoring restrictions. There have been at least three large vessel anchoring incidents since 1994. In 2002, the FGBNMS became the first international "no-anchor zone" through the development of new language integrated by the International Maritime Organization. Managers hope this designation will prevent future illegal anchoring incidents.

## Marine Debris

Impacts to various habitats within the Sanctuary from marine debris have been documented through recent remotely operated vehicle (ROV) and SCUBA surveys. Seismic cables (Figure 7.11), defunct pipelines, longlines and shrimping nets have all been encountered in the FGBNMS. Stetson Bank is encompassed by a ring of higher relief outcroppings, making it especially prone to accumulation of marine debris, particularly nets and line. Although longlining and the use of nets for fishing or shrimping are not allowed within the Sanctuary, illegal nets have been observed covering delicate sponges and branching corals. Debris resulting from oil and gas extraction impacts seafloor habitats as well, and seismic cables have caused abrasions along the flanks of some areas of the coral reef caps.

It is suspected that debris will be found throughout the Sanctuary. Its abundance and spatial distribution is dependent upon several factors, including its origin/source, ocean currents, and physiographic characteristics. Understanding the amount, extent and types of debris in the FGBNMS is critical to the management of sanctuary resources and is a prerequisite to targeting cleanup, prevention and education efforts. Monitoring surveys undertaken by NOAA's Center for Coastal Monitoring and Assessment, Biogeography Branch (CCMA-BB) and the FGBNMS staff provided an initial characterization of the prevalence of marine debris at the FGBNMS, and initial results from those surveys can be found in the Benthic Habitat section of this chapter.

## Aquatic Invasive Species

In August 2002, an invasive coral species from the Pacific Ocean, *Tubastraea coccinea*, was photographed at the EFGB on reef substrate at around 24 m depth (Figure 7.12). Prior to this discovery, no evidence of the coral had been reported on natural reef substrate in the Gulf of Mexico. However, it was known to inhabit the underwater structures of at least seven oil and gas platforms off the Texas coast. The first known sighting of *T. coccinea* on platforms in the Gulf occurred in 1991, and it was later documented on several other platforms (Fenner, 2001; Fenner and Banks, 2004). This coral species currently thrives on High Island A389A (HIA389A), a gas platform located within the EFGB boundaries. Since this initial discovery, at least two additional colonies have been documented at the EFGB. In September 2004, several dozen colonies of *T. coccinea* were also documented by the FGBNMS research team at Geyer Bank, located 52 km east-southeast of the EFGB. In May 2007, the FGBNMS documented over 100 colonies thriving at Geyer Bank. Several colonies were also documented at Sonnier Bank. This is further evidence of the threat to natural reef ecosystems by this invasive species.

A Pacific species of nudibranch (*Thecacera pacifica*) was first documented at Stetson Bank by Joyce Burek in 2006. The pair shown in Figure 7.12 was photographed during reproduction, so it is possible that this species may be proliferating. It is unknown how this invasive species will impact Stetson Bank ecosystem dynamics.

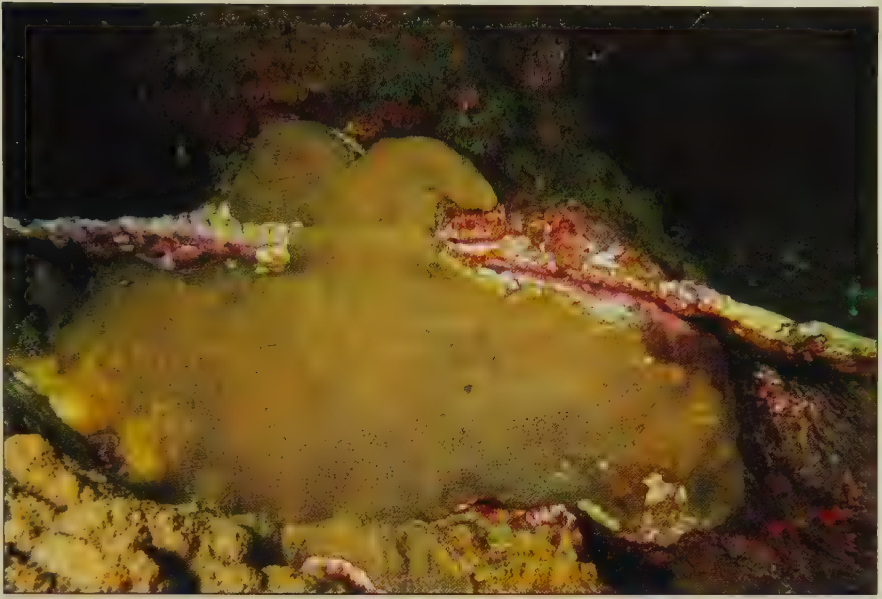


*Figure 7.11. Seismic cable overgrown by coral on the crest of the reef. Photo: Joyce and Frank Burek.*

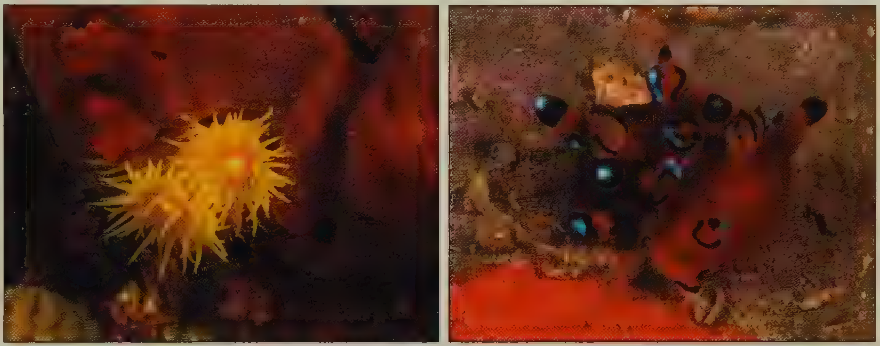


*Figure 7.12. Orange cup coral,* Tubastraea coccinea, *is an invasive species from the Pacific and was found growing on the reef cap at the EFGB (left). A Pacific species of nudibranch,* Thecacera pacifica, *was photographed at Stetson Bank (right). Photos: Joyce and Frank Burek.*

## Offshore Oil and Gas Exploration

The northern Gulf of Mexico is one of the most active areas for oil and gas exploration and development in the world. The Gulf of Mexico Outer Continental Shelf accounts for 25% of the oil and 14% of the natural gas produced in offshore U.S. waters (J. Sinclair, pers. comm.). By the end of 2007, 6,801 production platforms had been installed (of which approximately 2,910 were removed), about 47,969 wells had been drilled (including dry holes), and 63,400 km of pipeline installed (Figure 7.13).

Within the four-mile zones of both the EFGB and WFGB, which are regulated by the U.S. Department of the Interior, Minerals Management Service (MMS), there are currently 14 production platforms (six at the WFGB and eight at the EFGB, including one subsea station) and approximately 184.31 km of pipeline, 131.12 (71%) of which are dedicated gas pipelines. One platform and ap-

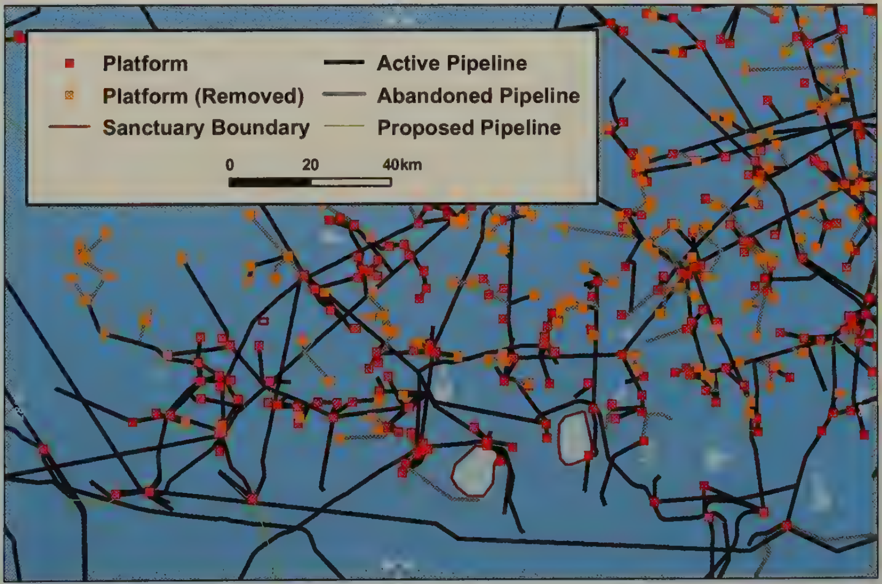


*Figure 7.13. Oil and gas infrastructure in the vicinity of the FGBNMS. Map: K. Buja.*

proximately 13.48 km of pipeline is located within a 6.5 km radius of Stetson Bank. Approximately fifteen decommissioned platforms have been converted to artificial reef sites in the vicinity of the FGBNMS.

There is one gas production platform (HIA389A) located within the EFGB boundary, less than 2 km from the coral cap (Figure 7.14). Recent exploration activities have been conducted by this platform. A pipeline has been constructed through the Sanctuary to link HIA389A to a subsea station outside Sanctuary boundaries. This pipeline will be used to transfer product from the subsea station to HIA389A for processing and shipment to shore.

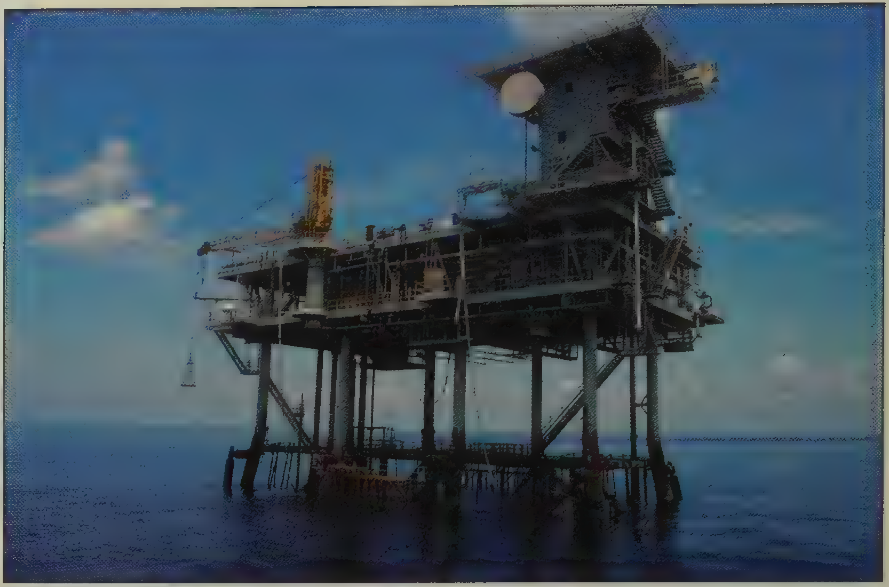


*Figure 7.14. An operational gas platform within the boundaries of the FGBNMS. Photo: FGBNMS/G.P. Schmahl.*

Potential impacts from offshore oil and gas exploration and development include accidental spills, contamination by drilling, related effluents and discharge, anchoring of vessels involved in placing pipelines, drilling rigs and production platforms, seismic exploration, use of dispersants in oil spill mitigation and platform removal. In spite of the intense industrial activity, long-term monitoring studies indicate no significant detrimental impact to the coral reefs of the FGBNMS from nearby oil and gas development (Gittings, 1998). Fortunately, there have been no major oil spills or impacts from these activities.

While the structures of the platform appear to provide artificial substrate for both motile and sessile marine populations, there is growing concern that the oil and gas structures may act as vectors for the spread of invasive and exotic species. An example is the introduction and establishment of sergeant majors (*Abudefduf saxatilis*) at the FGBNMS in 1997 and the recent appearance of yellowtail snapper (*Ocyurus chrysurus*). Pattengill (1998) suggests that these resulted from "hopping" along platforms in the eastern Gulf, where they have been reported by recreational fishers. We suspect that this is also the vector used by the orange cup coral (*T. coccinea*) to colonize the EFGB.

## CORAL REEF ECOSYSTEMS—DATA-GATHERING ACTIVITIES AND RESOURCE CONDITION

### *East and West Flower Garden Banks, Long-Term Monitoring Project*

Since 1989, the coral caps of the East and West Banks of the FGBNMS have been monitored annually through a contract funded cooperatively by the FGBNMS and MMS. Since 2002, the contract has been held by a group led by PBS&J, Geo-Marine, Inc. and Dauphin Island Sea Lab. Monitoring of Stetson Bank is not included in the contract. Table 7.1 lists these activities, as well as the monitoring activities undertaken at the FGBNMS by other organizations.

*Table 7.1. Table of assessment and monitoring activities. Source: E. Hickerson.*

| PROGRAM | OBJECTIVES | START DATE | FUNDING | PARTNERS |
|---|---|---|---|---|
| FGBNMS Long-Term Monitoring | Long-term monitoring of benthos, fish, lobster and *Diadema* at the East and West FGB | 1988 | FGBNMS, MMS | PBS&J, GeoMarine, Inc., Dauphin Island Marine Lab |
| Stetson Bank Long-Term Monitoring | Long-term monitoring of the coral pinnacle area at Stetson Bank | 1993 | FGBNMS | TAMUG, TPWD, various volunteer divers |
| Biogeographic Characterization of Fish Communities within the FGBNMS | Randomly selected benthic and fish transects on the reef cap and deep water habitats | 2006 | NCCOS, NOAA, FGBNMS | NCCOS, CCMA Biogeography Branch |
| REEF fish surveys | Roving diver surveys | 1996 | REEF, FGBNMS | REEF |
| AGRRA surveys | Conduct rapid assessment of the benthic community | 1999 | FGBNMS, AGRRA | AGGRA |

AGRRA – Atlantic and Gulf Rapid Reef Assessments
CCMA – Center for Coastal Monitoring and Assessment
FGBNMS – Flower Garden Banks NMS
NCCOS – National Centers for Coastal Ocean Service
REEF – Reef Environment Education Foundation
TAMUG – Texas A&M University – Galveston
TPWD – Texas Parks and Wildlife

The FGBNMS Long-Term Monitoring (LTM) Project is conducted within one hectare (ha; 100 x 100 m area) study sites located on the coral caps at EFGB and WFGB (Figure 7.15). The study evaluates water quality (temperature, salinity, light attenuation, pH, turbidity, dissolved oxygen), reef diversity, coral growth rates, long-term changes in individual coral colonies, accretionary growth, general coral reef community health, and fish, lobster and *Diadema* populations. Water samples are analyzed for nitrogen, nitrate, nitrite, dissolved ammonia, soluble reactive phosphorus, total phosphorus and chlorophyll a. Though the study quantifies a number of important parameters, the one hectare study sites do not encompass all reef habitat types found in the FGBNMS, such as the *Madracis mirabilis* fields. This fact was highlighted as a weakness of the monitoring effort after it was discovered that the fields had been catastrophically impacted during the passage of Hurricane Rita, yet the decline was not detected by the LTM project results.

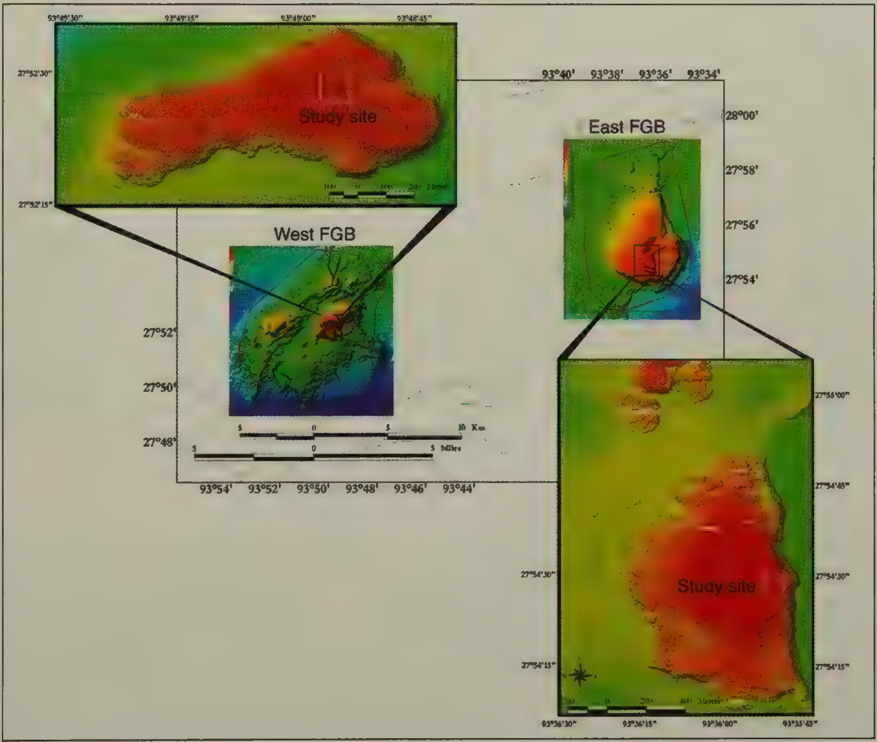


*Figure 7.15. The location of study areas for the FGBNMS long-term monitoring project. Source: Gardner et al., 1998; D. Weaver.*

### *Atlantic and Gulf Rapid Reef Assessment Surveys*

Benthic and fish communities at one site on each of the EFGB and WFGB were assessed using the Atlantic and Gulf Rapid Reef Assessment (AGRRA) protocol in August 1999.

### *Reef Environmental Education Foundation Fish Surveys*

The Reef Environmental Education Foundation (REEF) conducts fish surveys annually at the FGBNMS using roving diver surveys. The surveys do not quantify the abundance or biomass of the fish community, but all observations are entered into the REEF database. Methods and data are available at http://www.reef.org.

### *CCMA-BB Characterization of Fish and Benthic Communities at the FGBNMS*

Since 1998, CCMA-BB has been working to characterize, monitor and assess tropical ecosystems throughout the U.S. Caribbean and Pacific. This work has resulted in the development of a wide range of products, including maps, peer-reviewed publications, integrated assessments, and a publicly accessible database and Web site. The ongoing collaboration with FGBNMS is closely related to these activities, providing some level of comparability among study sites.

Between September 13 and October 1, 2006, CCMA-BB and FGBNMS launched the collaboration with a research mission on board the NOAA ship R/V *Nancy Foster*. The purpose of this mission was threefold: 1) to provide the Sanctuary with a spatial characterization of fish and benthic communities; 2) to optimize a sampling design for use in future resource monitoring efforts; and 3) to provide a baseline assessment of resource status against which future change can be monitored. The sampling approach utilized by the project relies on stratified random sampling at bank top habitats shallower than 110 ft. Using strata based on location (EFGB and WFGB) and slope (flat and steep), a total of 73 random sites throughout both the EFGB and WFGB were selected for surveys (Figure 7.16). This approach complements the permanent sites surveyed as part of the FGBNMS LTM by providing a more spatially comprehensive examination of sanctuary resources. Subsequent analyses revealed that a more efficient design incorporating both depth and habitat complexity in addition to the bank strata will further optimize sampling. Information on fish species abundance, size and distribution was collected along with data describing benthic habitat composition, coral bleaching and marine debris. An additional 33 sites were surveyed during September 2007 and are currently being analyzed to further characterize the Sanctuary's coral cap community. More project details are available at http://ccma.nos.noaa.gov/ecosystems/sanctuaries/fgb_nms.html.

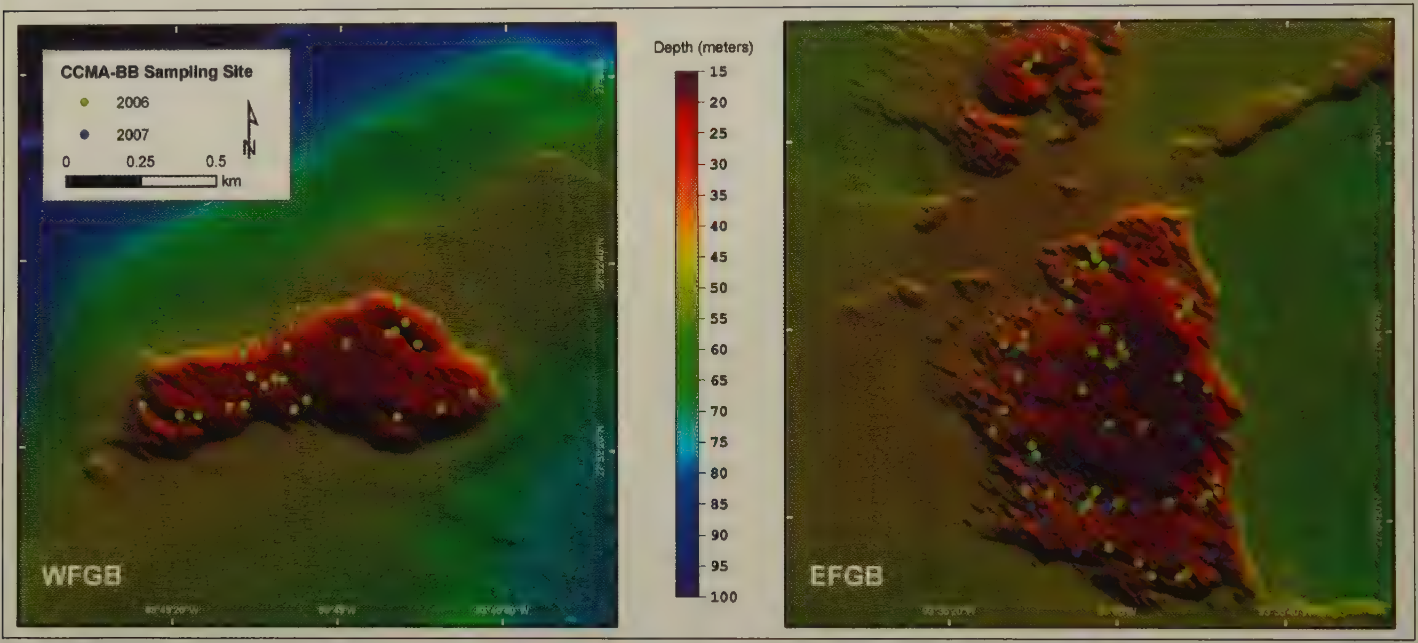


Figure 7.16. The location of stations surveyed by CCMA-BB in 2006 and 2007. Source: CCMA-BB; Map: B. Costa.

### *Other Sanctuary Activities*

In addition to the programs which are summarized in Table 7.1, the FGBNMS supports (by providing shiptime on chartered or Sanctuary vessels) several researchers investigating a wide array of topics. A list of the research projects can be downloaded from: http://flowergarden.noaa.gov/document_library/sci_documents.html. In addition, the Sanctuary research team conducts an annual data collection cruise at Stetson Bank, but funding limitations have precluded data analysis to date. Sanctuary staff encourage recreational divers to submit observations of charismatic megafauna, such as sharks, rays and sea turtles, since observations are maintained in the Sanctuary's database.

The most recent data available from the FGBNMS LTM Project and CCMA-BB/FGBNMS surveys are presented below to characterize the status of benthic habitats and biological communities at the FGBNMS. The combination of these project results best describes the status of the resources, with limitations as noted below.

## WATER QUALITY AND OCEANOGRAPHIC CONDITIONS

YSI 6600 Datasondes are deployed at the reef crests of all three banks of the FGBNMS. Sensors log the following measurements at 30 minute intervals: temperature, salinity, photosynthetically active radiation (PAR) irradiance, pH, turbidity and dissolved oxygen. Weather conditions and access to the site permit only quarterly servicing, however, due to fouling, limited memory capacity, etc., more regular servicing is recommended. Anomalies in the data sets prevent reporting of the data, with the exception of temperature. In addition to the deployment of the Datasondes, quarterly water sampling is conducted at the surface, midwater and near bottom. Additional temperature and salinity instruments were deployed on the reefs in the fall of 2007.

In 2005, water temperatures at the FGBNMS ranged from 21.46 to 30.93°C (mean =26.60°C ± 0.13% SE, n=349) at the EFGB and 21.11 to 30.45°C (mean=24.62°C ± 0.14 SE, n=304) at the WFGB. In June and July 2005, seawater temperature at the EFGB and WFGB oscillated between 25 and 28°C before increasing steadily to reach peak annual temperatures in August (Figure 7.17).

The temperature threshold for bleaching at the FGB is 30°C (Hagman and Gittings, 1992). Seawater temperature exceeded 30°C on the reef caps for extended periods at both banks in 2005. At the EFGB, average daily temperature was ≥ 29.5°C from July 29-September 19, 2005 (53 consecutive days). During that time, temperature exceeded 30°C during 29 days (including 16 consecutive days). At the WFGB, temperature on the reef cap was ≥ 29.5°C from July 26-August 22, 2005 (29 days) and temperature exceeded 30°C during seven days from August 6-21, 2005.

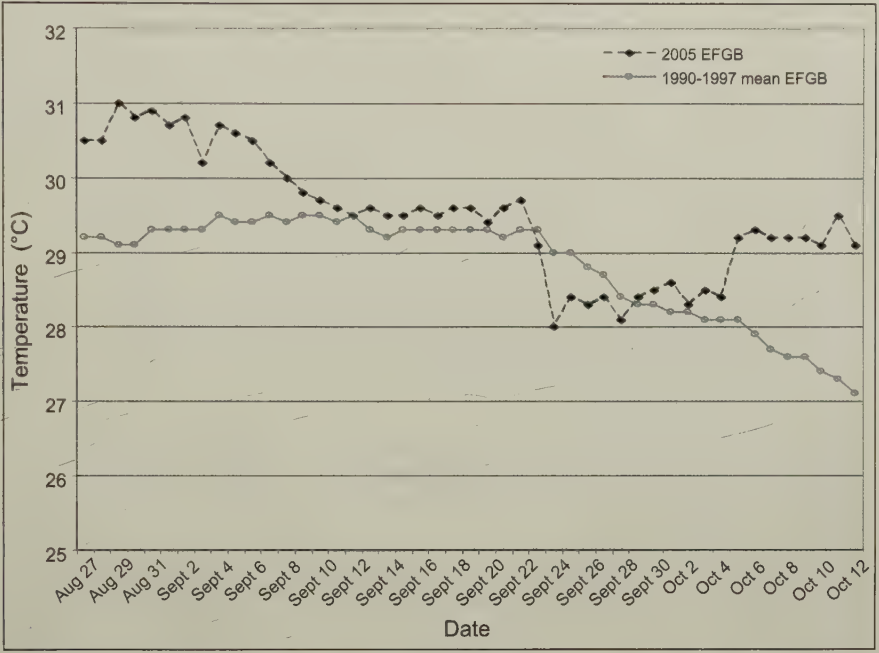


*Figure 7.17. Temperature measurements at depth at the EFGB and Stetson Bank during the passage of Hurricanes Katrina and Rita in 2005. Source: FGBNMS/NASA/NOAA CoastWatch/PBS&J.*

The temperature and salinity conditions that were experienced by the FGBNMS during Hurricanes Katrina and Rita events are worth noting. During the passage of Hurricane Katrina (August 28-29, 2005) temperature on the reef cap exceeded 30°C at the EFGB. HOBO temperatures indicated a slight increase in water temperature as Katrina passed through the region, but temperatures leveled off within a week. With the passage of Hurricane Rita in late September there was a sudden drop in temperature on the reef caps of the East Bank and West Bank. The temperature dropped from 29.6°C at 0033 hours to 27.4°C at 1933 hours. Temperature rose gradually after the passage of the hurricane. By 0733 hours on September 24, 2005 the temperature on the reef cap was up to 28.4°C

Salinity measurements for Stetson Bank and EFGB are compared in Figure 7.18. During both hurricane events, a drop in salinity is noted. The most dramatic drop was recorded at Stetson Bank after the passage of Hurricane Rita, from 35.4 parts per thousand (ppt) to 32.7 ppt over a period of 10 days. This can be first attributed to the immediate fresh water input into the system from the storm, and subsequent recovery, as seen in EFGB data. Stetson Bank, which is closer to shore, was most likely affected on a prolonged basis due to fresh water influences resulting from the water mass that moved offshore from the Texas/Louisiana coast through the FGBNMS.

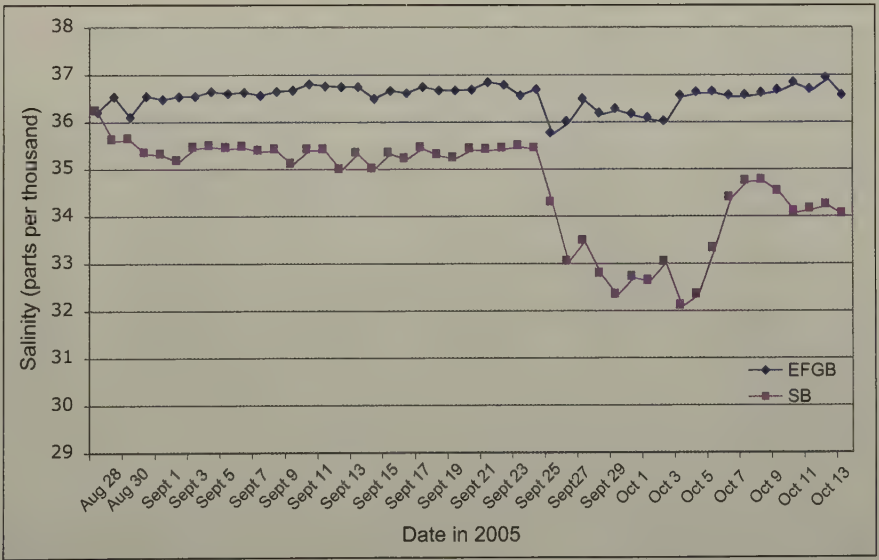


*Figure 7.18. Salinity measurements at the EFGB and Stetson Bank (SB) during the passage of Hurricanes Katrina and Rita in 2005. Source: FGBNMS/NASA/NOAA CoastWatch/PBS&J.*

## BENTHIC HABITATS

### *East and West Flower Garden Banks, Long-Term Monitoring Project*

One hectare study sites were established at both the EFGB and WFGB in 2002, and virtually all LTM monitoring occurs within these areas. The following is a description of the methods outlined in the statement of work for the contracted monitoring effort co-funded by FGBNMS and MMS (MMS Document: NSL-GM-04-06; GOMC4100, Section C). The monitoring includes several elements:

- **Random Photographic Transects:** 16 random photographic and/or digital video transects that are 10 m in length. Mean percent cover and standard deviation for each year and bank are calculated for coral species and other cover categories;
- **Permanent Growth Stations:** Photographs of 60 permanent stations for monitoring growth of the scleractinian coral *Diploria strigosa*;
- **Repetitive Quadrat Stations:** Forty repetitive photoquadrat stations to detect and evaluate long-term changes in individual coral colonies. In addition to the initial 40 stations, nine repetitive quadrat stations have been established at the EFGB in coral reef habitat at deeper depths (30-40 m);
- **Sclerochronology:** Cores of *Montastraea faveolata* coral colonies are taken biannually on each bank in odd numbered years to determine annual growth; and
- **Bleaching Incidence**: Percent cover of bleaching was calculated using random-dot analysis with CPCe® software. To obtain a percent cover value per bank in a particular year the total number of dots within a category (e.g., bleaching) was divided by the total number of dots analyzed for all repetitive quadrats minus the number of dots that fell on tape, wand and shadow.

*Results and Discussion*

The results presented here are from the FGBNMS long-term monitoring report covering the years 2002-2003 (Precht et al., 2005), 2004-2005 (Precht et al., 2008a) and data from 2006, which will be incorporated into the upcoming 2008 long-term monitoring report (Precht et al., unpub. data).

#### Community Composition and Structure

Monitoring results for 2002-2006 highlighted the continued health of these reefs, expressed as consistently high coral cover, which ranged from 49.55%–64.13% (Figure 7.19). These results are consistent with past monitoring results as well (Figure 7.20). The *Montastraea annularis* complex persisted as the dominant species complex from 2002-2006 (26.8-40.12%), and *Diploria strigosa* (3.2-13.41%) continued to be the second most prevalent species at both banks. Other coral species are represented at the EFGB and WFGB, including *Porites astreoides* (3.39-8.19%) and *Montastraea cavernosa* (2.25-7.73%). After these top four coral species, ten additional species make up the remainder of coral cover within the random transects (Table 7.2).

Macroalgae cover ranged from 4.06%–34.03% from 2002-2006, with the highest value recorded at the East Bank in 2005. Seasonal variation in macroalgal populations is well documented, so it should be noted that in 2005 and 2006 monitoring took place in June instead of during the normal fall (September-November) sampling period. From 2002-2004 macroalgal cover ranged from 4.06-19.14% across both banks, while from 2005-2006 macroalgal cover ranged from 12.5% to 34.03%. When comparing macroalgae estimates between

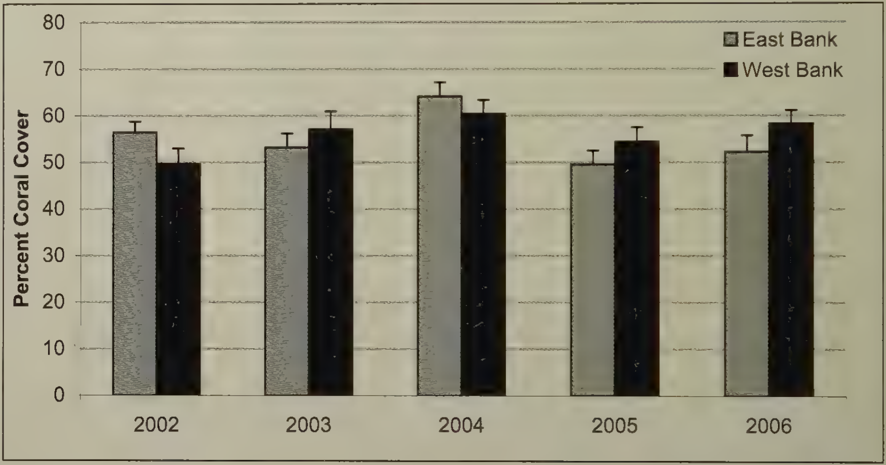


Figure 7.19. Mean percent coral cover at the FGB 2002-2006. Source: PBS&J, unpub. data.

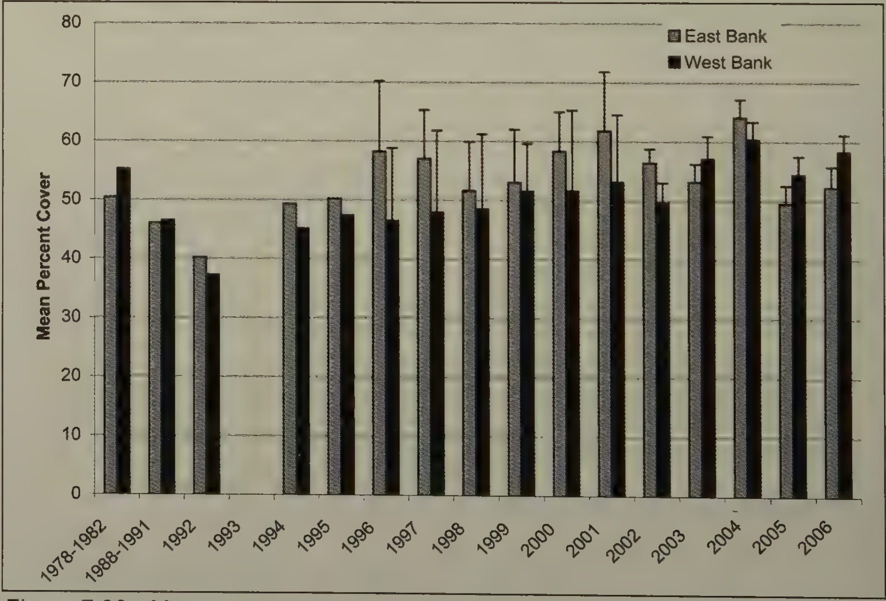


Figure 7.20. Mean percent coral cover at the FGB over time, showing the consistently high coral cover. No percent cover data were reported in 1993. Data sources by year: 1978-1982 from Gittings et al. (1992); 1988-1991 from Gittings et al., (1992); 1992-1995 from MMS (1996); 1996-2001 from Dokken et al. (2003); 2002-2003 from Precht et al., 2005; 2004-2005 from Precht et al. (in press).

*Table 7.2. Random transect coral cover by species at the EFGB and WFGB between 2002 and 2006. Values are expressed as percent cover ± SE. Source: PBS&J, unpub. data.*

| **COVER CATEGORY** | **EAST FLOWER GARDEN BANK** | | | | | **WEST FLOWER GARDEN BANK** | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **2002** | **2003** | **2004** | **2005** | **2006** | **2002** | **2003** | **2004** | **2005** | **2006** |
| *Agaricia agaricites* | 0.53 ± 0.15 | 0.33 ± 0.11 | 0.3 ± 0.12 | 0.11 ± 0.07 | 0.08 ± 0.03 | 0.43 ± 0.11 | 0.24 ± 0.08 | 0.29 ± 0.11 | 0.24 ± 0.07 | 0.13 ± 0.06 |
| *Agaricia fragilis* | 0.00 | 0.01 ± 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| *Colpophyllia natans* | 0.57 ± 0.39 | 3.29 ± 1.40 | 2.81 ± 1.38 | 1.77 ± 1.08 | 1.73 ± 1.06 | 1.67 ± 1.21 | 2.17 ± 0.84 | 3.48 ± 1.56 | 1.4 ± 0.54 | 0.55 ± 0.28 |
| *Diploria strigosa* | 6.96 ± 1.69 | 6.19 ± 1.55 | 12.13 ± 3.05 | 5.95 ± 1.26 | 10.25 ± 1.52 | 3.2 ± 0.91 | 9.04 ± 2.68 | 13.41 ± 1.74 | 6.68 ± 1.29 | 10.14 ± 1.64 |
| *Madracis* spp. | 0.66 ± 0.41 | 0.82 ± 0.34 | 0.7 ± 0.34 | 0.88 ± 0.38 | 0.18 ± 0.08 | 0.7 ± 0.47 | 0.37 ± 0.29 | 0.54 ± 0.42 | 0.08 ± 0.04 | 0.15 ± 0.10 |
| *Millepora alcicornis* | 2.19 ± 0.56 | 2.23 ± 0.43 | 1.41 ± 0.53 | 1.63 ± 0.59 | 0.46 ± 0.20 | 2.16 ± 0.70 | 1.94 ± 0.54 | 1.05 ± 0.51 | 1.68 ± 0.47 | 0.65 ± 0.20 |
| *Montastraea annularis* complex | 33.59 ± 3.86 | 28.47 ± 2.98 | 30.14 ± 5.14 | 26.8 ± 4.09 | 31.45 ± 4.09 | 31.73 ± 3.57 | 33.8 ± 4.31 | 31.70 ± 2.70 | 36.20 ± 3.50 | 40.12 ± 3.29 |
| *Montastraea cavernosa* | 3.9 ± 1.08 | 4.24 ± 1.41 | 7.73 ±2.09 | 3.4 ± 1.14 | 2.48 ± 0.67 | 2.74 ± 1.16 | 2.67 ± 1.10 | 3.7 ± 1.02 | 2.43 ± 0.69 | 2.25 ± 0.84 |
| *Mussa angulosa* | 0.37 ± 0.16 | 0.00 | 0.03 ± 0.02 | 0.07 ± 0.05 | 0.05 ± 0.04 | 0.29 ± 0.16 | 0.07 ± 0.04 | 0.16 ± 0.07 | 0.13 ± 0.08 | 0.24 ± 0.16 |
| *Porites astreoides* | 6.79 ± 0.83 | 5.69 ± 0.98 | 8.19 ± 1.07 | 7.55 ± 1.19 | 4.91 ± 0.83 | 3.44 ± 0.74 | 3.77 ± 0.46 | 5.19 ± 0.62 | 4.04 ± 0.46 | 3.39 ± 0.57 |
| *Porites porites forma furcata* | 0.06 ± 0.04 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 ± 0.01 | 0.00 | 0.00 | 0.00 | 0.00 |
| *Scolymia cubensis* | 0.00 | 0.01 ± 0.01 | 0.00 | 0.01 ± 0.01 | 0.00 ± 0.00 | 0.00 | 0.04 ± 0.03 | 0.00 | 0.01 ± 0.01 | 0.01 ± 0.01 |
| *Siderastrea siderea* | 0.44 ± 0.25 | 0.00 | 0.27 ± 0.29 | 0.6 ± 0.38 | 0.20 ± 0.13 | 1.9 ± 1.08 | 2.04 ± 1.10 | 0.00 | 1.1 ± 0.73 | 0.00 |
| *Stephanocoenia intersepta* | 0.31 ± 0.13 | 0.76 ± 0.32 | 0.33 ± 0.26 | 0.47 ± 0.47 | 0.31 ± 0.16 | 1.39 ± 0.36 | 0.96 ± 0.45 | 0.59 ± 0.27 | 0.00 | 0.44 ± 0.21 |
| **TOTAL CORAL** | **56.43 ± 2.36** | **53.20 ± 3.01** | **64.13 ± 3.03** | **49.55 ± 3.01** | **52.26 ± 3.50** | **49.67 ± 3.35** | **57.13 ± 3.81** | **60.41 ± 2.94** | **54.41 ± 3.13** | **58.28 ± 2.88** |

banks, West Bank results were consistently lower than East Bank values from 2003, 2005 and 2006 (Figure 7.21).

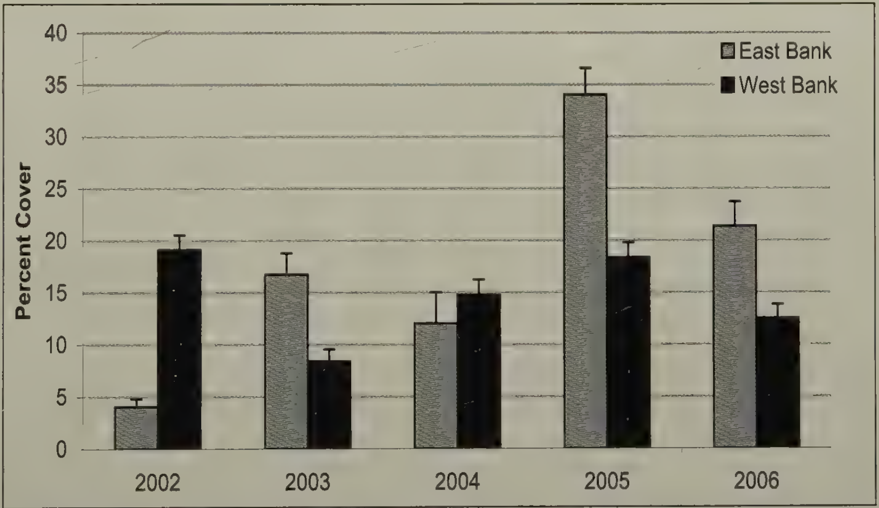


*Figure 7.21. Mean percent macroalgae cover at the FGB 2002-2006. Source: PBS&J, unpub. data.*

Crustose coralline algae, turf algae and bare space (CTB) showed a reciprocal relationship with macroalgae in all years at both banks (Figure 7.22 and 7.23). Between 2002 and 2006, CTB ranged from 11.96-37.07%, with the lowest values occurring at the East Bank in 2005 and the highest at the East Bank in 2002. CTB was higher at the West Bank than at the East Bank from 2003-2006.

On September 23, 2005 Hurricane Rita passed 50 miles east of East Bank on its way to the Texas coast. Although transect data was not taken during a post-hurricane assessment data collection cruise in November 2005, it was collected in June 2006. The June 2006 data revealed high CTB levels at East and West Bank (23.15% and 25.64%). Unexpectedly, macroalgae showed disparate patterns at East (21.36%) and West Bank (12.5%) in 2006.

Coral cover and changes in community structure were measured in November 2005 using repetitive quadrat images and perimeter video at the East Bank long-term monitoring site. Hurricane waves were responsible for overturning large coral colonies, scouring, gouging and the removal of sand from sand flats, as well as bending stainless steel rods on the reef cap (65-75 ft). Although there were dramatic effects of the hurricane at the East Bank, coral cover was not appreciably affected according to repetitive quadrat results. Approximately 1.5% of coral colonies were missing in the 40 repetitive quadrat photographs taken on the coral cap (70-85 ft), while only 0.5% of colonies were missing at nine deep repetitive quadrat stations (105-131 ft). Levels of coral bleaching were relatively high for the FGB (about 6% on the coral caps), but bleaching had been observed before the hurricane (NOAA cruise August 23-27), and it is not known whether the hurricane exacerbated bleaching or whether it may have brought relief in the form of cooler water temperatures. Water quality data results showed that the passage of Hurricane Rita brought cooler water temperatures to the banks after 50 days of elevated temperatures.

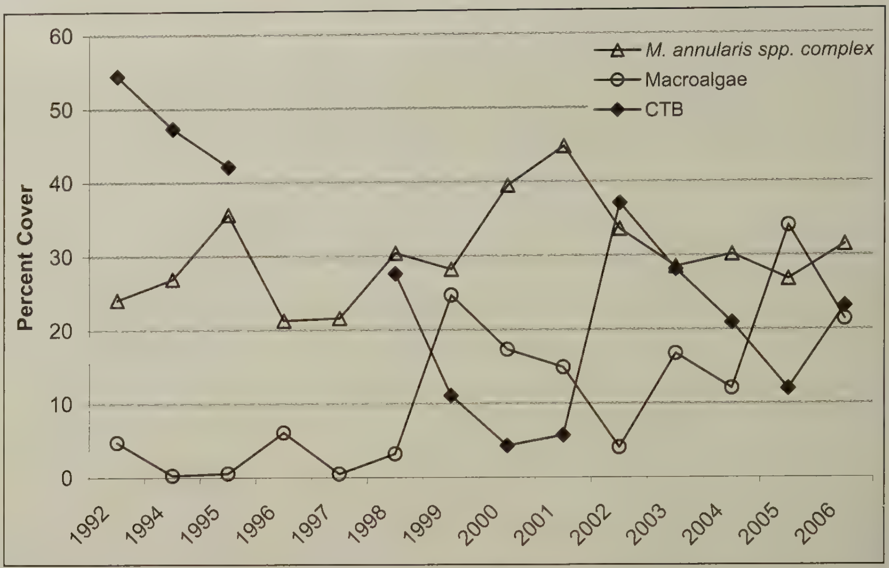


*Figure 7.22. East Bank percent cover of* Montastraea annularis *species complex, macroalgae and CTB 1992-2006. Source: PBS&J, unpub. data.*

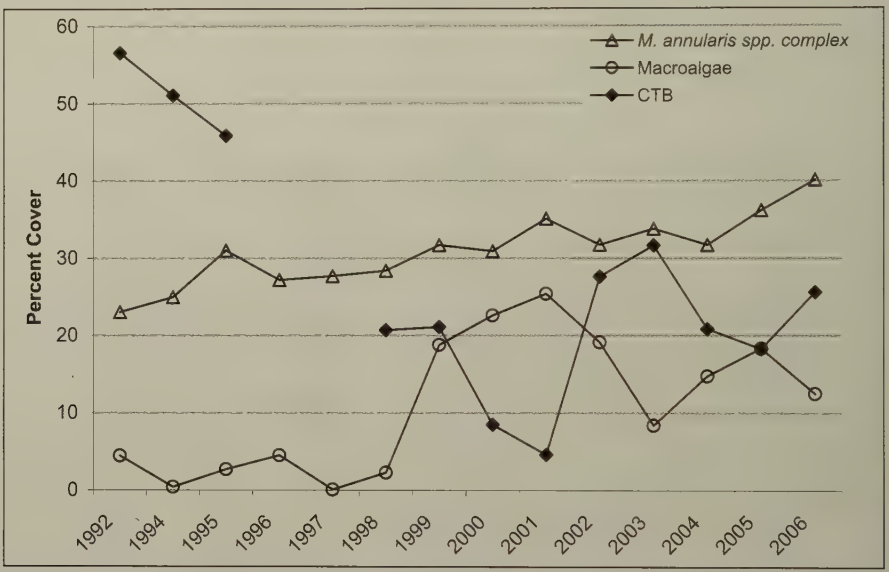


*Figure 7.23. West Bank percent cover of* Montastraea annularis *species complex, Macroalgae and CTB 1992-2006. Source: PBS&J, unpub. data.*

**Permanent Growth Stations (2002-2003):** A total of eight analyses were completed for the East Bank, with four colonies advancing and four colonies retreating in lateral growth. At the West Bank there was a total of four analyses completed, two colonies grew laterally and two colonies showed lateral retraction. Due to the low sample size there was not enough data to draw conclusions about change in lateral growth of *Diploria strigosa* margins at the EFGB and WFGB.

**Permanent Growth Stations (2004-2005):** A total of 30 analyses were completed for the EFGB, with nine advances and 21 retreats recorded. A total of 25 analyses were completed for the WFGB, with 16 advances and nine retreats. Growth of *D. strigosa* margins was significantly greater on the West Bank than on the East Bank in 2004-2005 (ANOVA t=2.64, df=43, p=0.011). When pooling the data for the two banks, colony area increased 14% from 2004-2005.

**Permanent Growth Stations (2005-2006):** A total of 33 analyses were completed for the EFGB, with 22 advances and 11 retreats recorded. A total of 51 analyses were completed for the WFGB, with 34 advances and 17 retreats. Overall, this represents a positive growth trend of *D. strigosa* growth margins for the sampling period.

**Repetitive Quadrat Stations (2002-2006):** Photoquadrats encompassing 8 m$^2$ are used to monitor changes in coral reef community structure over time. Percent cover data as well as planimetry are used to track corals over time and include measurements of coral cover, bleaching, and disease as well as planimetry measurements of specific coral colonies. In general percent coral cover in the surveyed area is high and exhibits similar species dominance to random transect data. Planimetry is used to measure the margins of individual coral colonies annually to determine changes in marginal growth. Because the *M. annularis* complex is the dominant substratum occupant in repetitive quadrats we compared the cover of this taxon through time.

Over the 2002-2006 sampling period there was an overall extension of growth margins of *M. annularis* complex in repetitive quadrat images. Coral colonies are traced each year and their change in lateral growth is measured as area (cm$^2$). A proportion is created in relation to the previous years measurement and yields a proportional increase or decrease in the colony area. These proportional changes are averaged per bank and reported below.

**Repetitive Quadrat Stations (2002-2003)**: Sixteen repetitive quadrats were paired and analyzed between 2002 and 2003 at the East Bank. Overall planimetry results showed a 15% growth or extension of margins of the *M. annularis* species complex at EFGB. At the West Bank, 27 images were paired and analyzed and showed an increase of 10% in *M. annularis* species complex.

**Repetitive Quadrat Stations (2003-2004)**: Thirty-eight stations were paired and analyzed between 2003 and 2004 at the East Bank. *M. annularis* complex colonies at the East Bank showed a slight decline in marginal growth by 4%. West Bank showed a similar recession of growth margins (5%).

**Repetitive Quadrat Stations (2004-2005)**: Thirty-six repetitive quadrat images were paired in 2004 and 2005 at the East Bank and the *M. annularis* complex colony margins showed expansion from 2004 to 2005 by 8%. At the West Bank, 20 photograph pairs were analyzed and showed a 3% extension of margins.

**Repetitive Quadrat Stations (2005-2006)**: Thirty-seven repetitive quadrat pairs were compared at the East Bank from 2005-2006, and a 12% increase in *M. annularis* complex margins was measured. West Bank results showed a 17% increase in growth margins from 2005-2006 after analysis of 27 repetitive quadrat pairs.

### *Sclerochronology*

Four coral cores are taken at each bank in odd years from *M. faveolata* colonies to monitor accretional growth of colonies over time. Estimated annual growth at the East Bank ranged from 3.19-14.54 mm/year from 1997-2005, with an average growth of 6.06 mm/year (Figure 7.24). At the West Bank growth rates ranged from 2.75-8.78 mm/year with an overall mean 5.53 mm/year. Mean annual growth rates were not significantly different between banks (t=0.96, df=19, p=0.35), however, a trend of lower growth rates occurs at the West Bank (Figure 7.24).

### Bleaching Incidence

Information on coral bleaching is collected under the LTM program and via belt transects surveyed periodically by FGBNMS staff. The LTM data is collected once a year, and applies the methodology described above to determine the incidence of bleaching.

In addition, the FGBNMS research team conducts rapid assessment surveys to collect information in response to specific events such as hurricanes, coral disease outbreaks and coral bleaching events. After the passage of Hurricanes Katrina and Rita, the FGBNMS conducted surveys at both the EFGB and WFGB in October and November 2005, and again in January and March 2006, to document damage from the hurricanes and coral bleaching event.

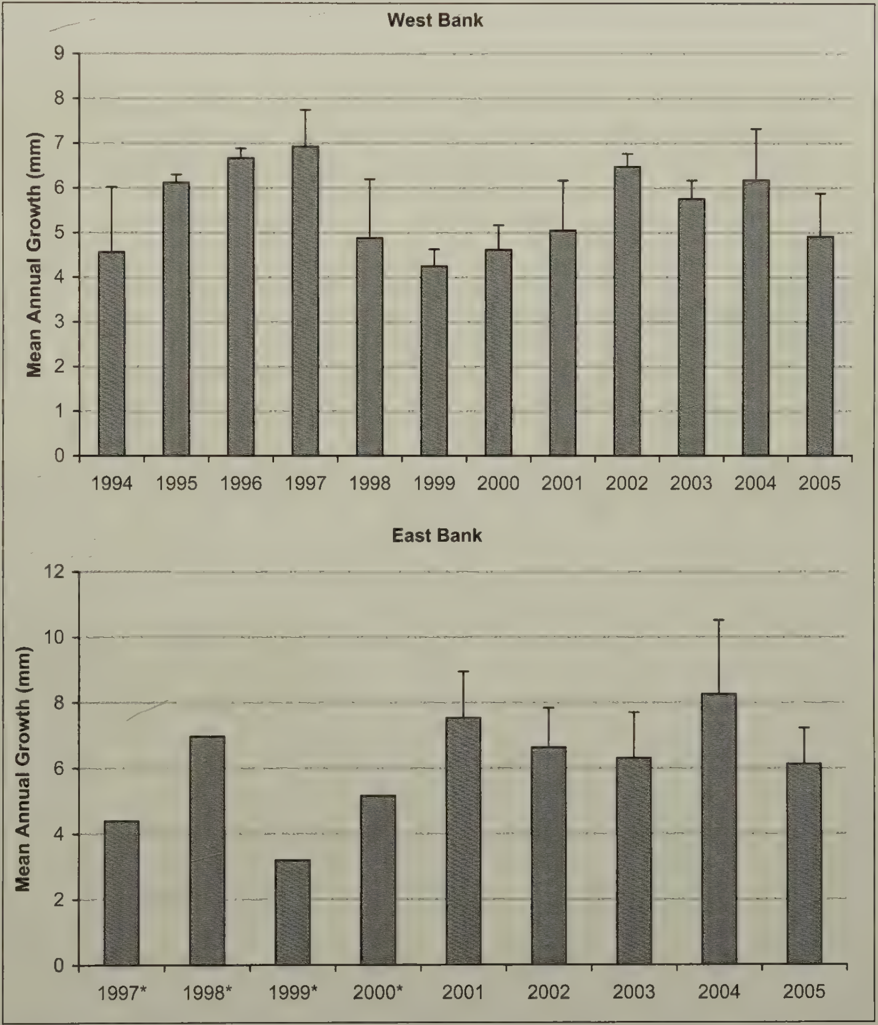


*Figure 7.24. Mean annual growth in mm for* Montastraea faveolata *colonies at WFGB (top) and EFGB (bottom). Asterisks indicate data estimated from a single measurement (n=1). Source: PBS&J, unpub. data.*

At multiple mooring buoys in the FGBNMS, researchers laid out 15 x 1 m belt transects, counted every coral colony and scored it according to its bleaching condition (totally bleached, partially bleached or unbleached). Based on these surveys, an average of 42% of the colonies were either partially or fully bleached in October 2005 and 46% were partially or fully bleached in November 2005. In January 2006 (4.5%) and March 2006 (4.0%) observations were similar at the WFGB, and continued recovery was documented at the EFGB; January (10.3%) and March (4.0%). The bleaching appeared to be affecting 100% of the fire coral (*M. alcicornis*) and great star coral (*M. cavernosa*), and affecting at least eleven other species to varying degrees. Long-term monitoring results have shown loss of fire coral due to the bleaching event.

## CCMA-BB Characterization of Fish and Benthic Communities at the FGBNMS

The partnership between CCMA-BB has provided an opportunity to characterize the Sanctuary's benthic habitats on a broader scale. This is in contrast to and complementary to the FGBNMS LTM contract that is primarily contained within a 100 x 100 m area on each of the EFGB and WFGB

### *Methods*

A total of 73 stratified random sampling sites were surveyed within the FGBNMS in 2006, and in 2007, 33 additional sites were sampled before Tropical Storm Humberto forced the ship from the area. Data from 2007 was not incorporated into this summary. Detailed information on benthic habitat composition in 2006 was recorded within four 1 m$^2$ quadrats located along a series of transects. Data were also collected to quantify the level of coral bleaching within the quadrats and note the prevalence of marine debris along the transects. Detailed *in situ* data collection methodologies are available at http://ccma.nos.noaa.gov/ecosystems/coralreef/reef_fish/protocols_fgb.html.

### *Results and Discussion*

Table 7.3 summarizes the benthic composition data. The overall coral cover for the East and West Bank were 53% and 59% respectively. These estimates are within 2% of those derived from the 2006 FGBNMS LTM effort. Percent cover of sponges falls within 0.15% of the FGBNMS LTM results while macroalgae estimates were greater during the FGBNMS LTM surveys by approximately 6% at EFGB and 14% at WFGB.

*Table 7.3. Benthic habitat composition data summarized by strata and overall. Source: CCMA BB, unpub. data.*

| LOCATION | SLOPE | NUMBER OF SURVEYS | PERCENT CORAL | | PERCENT MACROALGAE | | PERCENT SPONGES | |
|---|---|---|---|---|---|---|---|---|
| | | | Mean | ( + SE) | Mean | ( + SE) | Mean | ( + SE) |
| East Bank | Flat | 44 | 55 | 3.4 | 26 | 2.9 | 0.7 | 0.20 |
| | Steep | 5 | 34 | 9.4 | 41 | 11.1 | 0.6 | 0.42 |
| | **OVERALL** | 49 | 53 | 2.9 | 27 | 2.5 | 0.7 | 0.17 |
| West Bank | Flat | 19 | 61 | 4.3 | 25 | 3.7 | 0.4 | 0.14 |
| | Steep | 5 | 51 | 12.6 | 39 | 15.0 | 1.5 | 0.90 |
| | **OVERALL** | 24 | 60 | 3.4 | 27 | 3.0 | 0.6 | 0.12 |
| All FGBNMS | Flat | 63 | 57 | 2.0 | 26 | 1.7 | 0.6 | 0.11 |
| | Steep | 10 | 42 | 5.4 | 40 | 6.4 | 1.0 | 0.31 |
| | **OVERALL** | 73 | 55 | 1.7 | 27 | 1.5 | 0.7 | 0.09 |

*Table 7.4. Comparison of benthic habitat composition data between locations in the U.S. Caribbean and the FGBNMS. Source: CCMA-BB, unpub. data.*

| LOCATION | SURVEYS n= | PERCENT CORAL | | PERCENT MACROALGAE | | PERCENT SPONGES | |
|---|---|---|---|---|---|---|---|
| | | Mean | SE | Mean | SE | Mean | SE |
| FGBNMS | 73 | 55 | 1.7 | 28 | 19.9 | 0.7 | 0.09 |
| St Croix, USVI | 30 | 2 | 0.6 | 61 | 5.9 | 2.5 | 0.39 |
| St John, USVI | 51 | 8 | 1.0 | 51 | 3.0 | 7.2 | 0.78 |
| La Parguera, PR | 21 | 6 | 1.5 | 37 | 5.7 | 1.3 | 0.30 |

CCMA-BB collects identical data at other locations within the U.S. Caribbean. As a point of comparison the data for 2006 are summarized in Table 7.4. Only sites at or below 60 ft are included in the summary to limit depth as a factor. The largest difference between the locations is percent coral cover, which at 55% is nearly seven times that seen in St. John, USVI, the next closest value. In contrast to the low values for percent coral cover, a large portion of area in the U.S. Caribbean locations is dominated by marine plants and algae. All locations surveyed in the U.S. Caribbean are significantly closer to land and therefore likely to be more heavily influenced by factors such as sedimentation, contaminants, or human use. These factors either alone or in combination may be responsible for the differences observed.

## Atlantic and Gulf Rapid Reef Assessment (AGRRA)

This assessment was presented in the 2005 edition of this report.

## ASSOCIATED BIOLOGICAL COMMUNITIES

### *East and West Flower Garden Banks Long-Term Monitoring Project*

Fish counts were performed at both banks using stationary visual techniques for quantitatively assessing community structure of coral reef fishes (Bohnsack and Bannerot, 1986). A minimum of 24 surveys were performed at each bank to provide a statistically sound assessment of reef fish abundance and diversity. Survey sites were selected randomly from within the 1-hectare study locations at the EFGB and WFGB.

*Results and Discussion*

A mean of 21.5 diver surveys/samples (± 6.56 SD) were conducted during the 2004-2005 FGB survey efforts. Surveys were conducted during the day from 0700 hours through dusk. The 2004 data was gathered in September (East Bank) and November (West Bank). Data in 2005 was collected in June. The highest number of diver surveys/samples was conducted in 2004 at the West Bank, while the lowest occurred at the East Bank in 2004 (Table 7.5). Unfavorable weather conditions hampered survey efforts in 2004 and were the reason for the low number of fish surveys at the East Bank in 2004. An average of 38% of the 100 x 100 m study sites was visually surveyed during 2004-2005.

*Table 7.5. Visual fish survey sampling statistics for the East and West Banks in 2004 and 2005. Each survey covers 177 m$^2$. Source: PBS&J.*

| | 2004 EB | 2004 WB | 2005 EB | 2005 WB |
|---|---|---|---|---|
| Number samples (n) | 12 | 27 | 24 | 23 |
| Percent area of study site sampled | 21% | 48% | 42% | 41% |
| Sampled area (m$^2$) | 2,124 | 4,779 | 4,248 | 4,071 |
| Total fish abundance | 5,331 | 1,876 | 3,928 | 3,252 |

A mean of 57 fish species (± 6.0 SD) were observed during the 2004-2005 surveys. This is an increase from the 51 (± 3.5 SD) mean fish species recorded during the 2002-2003 surveys. A total of 85 fish species were recorded for all survey efforts combined at the FGB in 2004 and 2005 (Table 7.6). Comparison of species richness (number of species recorded per survey) between banks and years showed a similar pattern to fish abundance, with a significant difference between banks in 2004 but not in 2005, and a significant difference at East Bank, but not at West Bank, between 2004 and 2005. The highest mean richness recorded per diver survey was at East Bank in 2004 (mean richness=22 species/survey; Table 7.7).

*Table 7.6. Species list of fishes recorded in stationary visual surveys conducted at East and West Banks in 2004 and 2005. Fish are presented in descending order of numerical abundance. Source: PBS&J.*

| FISH SPECIES | FISH COMMON NAMES | FAMILY NAME | TROPHIC GUILD | NUMBER |
|---|---|---|---|---|
| *Chromis multilineata* | Brown chromis | Pomacentridae | Carnivore | 3599 |
| *Emmelichthyops atlanticus* | Bonnetmouth | Inermiidae | Planktivore | 3200 |
| *Clepticus parrae* | Creole wrasse | Labridae | Carnivore | 1442 |
| *Thalassoma bifasciatum* | Bluehead | Labridae | Carnivore | 711 |
| *Stegastes partitus* | Bicolor damselfish | Pomacentridae | Herbivore | 494 |
| *Stegastes planifrons* | Threespot damselfish | Pomacentridae | Herbivore | 439 |
| *Chromis cyanea* | Blue chromis | Pomacentridae | Carnivore | 326 |
| *Scarus vetula* | Queen parrotfish | Scaridae | Herbivore | 229 |
| *Halichoeres maculipinna* | Clown wrasse | Labridae | Carnivore | 207 |
| *Acanthurus coeruleus* | Blue tang | Acanthuridae | Herbivore | 195 |
| *Caranx ruber* | Bar jack | Carangidae | Carnivore | 189 |
| *Melichthys niger* | Black durgon | Balistidae | Omnivore | 160 |
| *Caranx hippos* | Crevalle jack | Carangidae | Carnivore | 159 |
| *Sparisoma viride* | Stoplight parrotfish | Scaridae | Herbivore | 149 |
| *Kyphosus sectator/incisor* | Bermuda/Yellow chub | Kyphosidae | Omnivore | 148 |
| *Scarus taeniopterus* | Princess parrotfish | Scaridae | Herbivore | 148 |
| *Canthidermis sufflamen* | Ocean triggerfish | Balistidae | Omnivore | 119 |
| *Inermia vittata* | Boga | Inermiidae | Planktivore | 101 |
| *Bodianus rufus* | Spanish hogfish | Labridae | Carnivore | 99 |
| *Elacatinus oceanops* | Neon goby | Gobiidae | Omnivore | 77 |
| *Mulloidichthys martinicus* | Yellow goatfish | Mullidae | Carnivore | 76 |
| *Acanthurus bahianus* | Ocean surgeonfish | Acanthuridae | Herbivore | 75 |
| *Scarus iseri* | Striped parrotfish | Scaridae | Herbivore | 71 |
| *Microspathodon chrysurus* | Yellowtail damselfish | Pomacentridae | Herbivore | 62 |

Table 7.6 (continued). Species list of fishes recorded in stationary visual surveys conducted at East and West Banks in 2004 and 2005.

| FISH SPECIES | FISH COMMON NAMES | FAMILY NAME | TROPHIC GUILD | NUMBER |
|---|---|---|---|---|
| *Sparisoma aurofrenatum* | Redband parrotfish | Scaridae | Herbivore | 62 |
| *Halichoeres garnoti* | Yellowhead wrasse | Labridae | Carnivore | 61 |
| *Stegastes variabilis* | Cocoa damselfish | Pomacentridae | Herbivore | 61 |
| *Chaetodon sedentarius* | Reef butterflyfish | Chaetodontidae | Herbivore | 57 |
| *Acanthurus chirurgus* | Doctorfish | Acanthuridae | Herbivore | 51 |
| *Mycteroperca tigris* | Tiger grouper | Serranidae | Carnivore | 48 |
| *Chaetodon ocellatus* | Spotfin butterflyfish | Chaetodontidae | Herbivore | 45 |
| *Bodianus pulchellus* | Spotfin hogfish | Labridae | Carnivore | 40 |
| *Abudefduf saxatilis* | Sergeant major | Pomacentridae | Herbivore | 30 |
| *Stegastes adustus* | Dusky damselfish | Pomacentridae | Herbivore | 29 |
| *Prognathodes aculeatus* | Longsnout butterflyfish | Chaetodontidae | Herbivore | 28 |
| *Ophioblennius atlanticus* | Redlip blenny | Blenniidae | Omnivore | 28 |
| *Caranx latus* | Horse-eye jack | Carangidae | Carnivore | 19 |
| *Holacanthus tricolor* | Rock beauty | Pomacanthidae | Herbivore | 19 |
| *Chaetodon striatus* | Banded butterflyfish | Chaetodontidae | Herbivore | 17 |
| *Stegastes leucostictus* | Beaugregory | Pomacentridae | Herbivore | 16 |
| *Lactophrys triqueter* | Smooth trunkfish | Ostraciidae | Omnivore | 14 |
| *Malacoctenus triangulatus* | Saddled blenny | Blenniidae | Omnivore | 13 |
| *Caranx lugubris* | Black jack | Carangidae | Carnivore | 12 |
| *Seriola dumerili* | Amber jack | Carangidae | Carnivore | 12 |
| *Holacanthus ciliaris* | Queen angelfish | Pomacanthidae | Herbivore | 11 |
| *Lutjanus jocu* | Dog snapper | Lutjanidae | Carnivore | 9 |
| *Elagatis bipinnulata* | Rainbow runner | Carangidae | Carnivore | 8 |
| *Holocentrus adscensionis* | Squirrelfish | Holocentridae | Carnivore | 8 |
| *Parablennius marmoreus* | Seaweed blenny | Blenniidae | Omnivore | 8 |
| *Amblycirrhitus pinos* | Redspotted hawkfish | Cirrhitidae | Carnivore | 7 |
| *Pomacanthus paru* | French angelfish | Pomacanthidae | Herbivore | 6 |
| *Halichoeres radiatus* | Puddingwife | Labridae | Carnivore | 5 |
| *Cantherhines macrocerus* | Whitespotted filefish | Monocanthidae | Herbivore | 4 |
| *Chromis insolata* | Sunshinefish | Pomacentridae | Planktivore | 4 |
| *Lutjanus griseus* | Gray snapper | Lutjanidae | Carnivore | 4 |
| *Acanthostracion polygonius* | Honeycomb cowfish | Ostraciidae | Omnivore | 3 |
| *Holocentrus rufus* | Longspine squirrelfish | Holocentridae | Carnivore | 3 |
| *Cantherhines pullus* | Orangespotted filefish | Monocanthidae | Herbivore | 2 |
| *Diodon hystrix* | Porcupinefish | Diodontidae | Carnivore | 2 |
| *Scarus coelestinus* | Midnight parrotfish | Scaridae | Herbivore | 2 |
| *Sparisoma chrysopterum* | Redtail parrotfish | Scaridae | Herbivore | 2 |
| *Stegastes diencaeus* | Longfin damselfish | Pomacentridae | Herbivore | 2 |
| *Aluterus schoepfi* | Orange filefish | Monocanthidae | Herbivore | 1 |
| *Equetus punctatus* | Spotted drum | Sciaenidae | Carnivore | 1 |
| *Gymnothorax moringa* | Spotted moray | Muraenidae | Carnivore | 1 |
| *Lactophrys bicaudalis* | Spotted trunkfish | Ostraciidae | Omnivore | 1 |
| *Sparisoma atomarium* | Greenblotch parrotfish | Scaridae | Herbivore | 1 |
| *Sparisoma rubripinne* | Redfin parrotfish | Scaridae | Herbivore | 1 |

Table 7.7. Species and family richness and density values for the East and West Banks recorded during 2004 and 2005 survey efforts. Source: PBS&J.

| | 2004 EB | 2004 WB | 2005 EB | 2005 WB |
|---|---|---|---|---|
| Total Species (Species Richness) | 55 | 50 | 64 | 60 |
| Total Families (Family Richness) | 18 | 19 | 22 | 21 |
| Mean Abundance/Survey | 444.25 | 69.48 | 163.66 | 141.39 |
| ^SD | 275.36 | 35.62 | 101.64 | 79.29 |
| Mean Abundance/ m$^2$ | 2.51 | 0.39 | 0.97 | 0.8 |
| Mean Species Richness/Survey | 22 | 14.96 | 17.21 | 16.61 |
| ^SD: | 4.22 | 6.15 | 2.75 | 3.07 |
| Mean Spp Richness/ m$^2$ | 0.12 | 0.08 | 0.1 | 0.09 |
| Mean Family Richness | 11.5 | 8.71 | 9.79 | 9.74 |
| ^SD | 2.11 | 2.88 | 1.91 | 1.79 |
| Mean Family Richness/ m$^2$ | 0.07 | 0.049 | 0.06 | 0.06 |

Mean fish abundance per area ranged from a high at the East Bank in 2004 of 251.39/100 m$^2$ to a low at the West Bank in 2004 of 39.32/100 m$^2$ (Table 7.7). Mean density values in 2005 were 96.64 at EFGB and 80.01/100 m$^2$ at WFGB. In previous years, the mean density value for the East Bank has fluctuated from 82.78/100 m$^2$ in 2002 to 157.53/100 m$^2$ in 2003. Previous mean density values recorded in 2002 and 2003 at the West Bank were 73.29 and 84.62/100 m$^2$ respectively.

Fish abundance (mean fish abundance recorded per survey) showed a significant difference (t=7.056, df=37, p=2.38 x $10^{-08}$) between the East and West Banks in 2004, but not in 2005. The East Bank showed a significant difference (t=4.470, df=34, p=8.26 x $10^{-05}$) in fish abundance between the years 2004 and 2005, but no significant interannual difference was found at the West Bank. The high density value for the East Bank in 2004 is attributed to the high numbers of the small schooling Inermiidae species, *Emmelichthyops atlanticus*. The mean observed abundance for *E. atlanticus* was 266.67 fish/survey (± 271.64 SD), corresponding to a mean density value of 150.9 fish/100 m$^2$. *Clepticus parrae*, *Chromis multilineata* and *Paranthias furcifer* were also observed in high densities at the East Bank in 2004 with mean density values of 20.37, 19.38 and 13.06/100 m$^2$ respectively. Density values of *C. multilineata* and *C. parrae*, which ranked as the top two most abundant species at the East Bank in 2005, were 37.87 and 9.41/100 m$^2$ respectively. Also ranked as the top two most abundant species at the West Bank in 2005, their density values there were 34.08 and 9.87/100 m$^2$.

*C. multilineata* and *C. parrae* were consistently the two most abundant species in 2004 and 2005, with the exception of 2004 when *E. atlanticus* was recorded in greater numbers than these fish the East Bank. Additionally, *P. furcifer*, *Thalassoma bifasciatum* and *Stegastes partitus* were regularly ranked among the top five most abundant species.

The sighting frequency of fish species varied between years and banks as they did during the 2002-2003 surveys. However, the species most frequently recorded per survey throughout the 2004-2005 surveys were *C. multilineata*, *Stegastes planifrons*, *S. partitus*, *Scarus vetula*, *T. bifasciatum*, *Acanthurus coeruleus* and *C. parrae*.

The number of fish families observed fell to an average of 20 fish families per bank, down from an average of 21 families observed during the 2002-2003 surveys. The most abundant families observed were the Labridae, Pomacentridae, Serranidae and Scaridae. Mean densities of fish in the family Labridae ranged from 8.80–31.60/100 m$^2$ at the West and East Banks, respectively, in 2004. Pomacentridae densities ranged from 15.50/100 m$^2$ at the West Bank in 2004 to 49.51/100 m$^2$ at the East Bank in 2005. Scaridae ranged in density from 2.73/100 m$^2$ at the West Bank in 2005 to 7.40/100 m$^2$ at the East Bank in 2004.

Families represented by the most species were the Pomacentridae, Labridae, Serranidae and Scaridae. The most species of Pomacentridae were recorded in 2005 at the East Bank with 12 representatives, while the fewest were recorded in 2004 with eight representative species. The greatest number of species of Serranidae were observed in 2005 at the West Bank with nine species. The number of Scaridae species was consistent, ranging from five recorded in 2004 at the West Bank to seven at the East Bank in 2005. The Labridae family was generally represented by seven species.

The Pomacentridae family was represented by a mean of 4.00 species/survey at the West Bank in 2005, while 4.58 species/survey were recorded at the East Bank in 2004. The most common representatives of the Pomacentridae family were *Chromis mulitilineata*, *C. cyanea*, *Stegastes partitus* and *S. planifrons*. The Labridae family was represented by a mean of 2.65 species/survey at the West Bank in 2005 and 3.67 species/survey at East Bank sites in 2004. The most common representatives of the Labridae family were *C. parrae*, *T. bifasciatum* and *Bodianus rufus*. Scaridae were represented by a mean of 1.78 species/survey at the West Bank in 2004 and a mean of 3.00 species /survey at the East Bank. The most common representatives of the Scaridae family were *Scarus vetula*, *S. taeniopterus*, *Sparisoma viride*, and *S. aurofrenatum*. The Serranidae family was represented by a mean of 0.63 species/survey at the West Bank in 2004 and 1.83 species/survey at the East Bank. *P. furcifer* was by far the most common representative of the Serranidae family; however, others included *Cephalopholis cruentata*, *Epinephelus adscensionis* and *Mycteroperca tigris*.

Fish in the family Acanthuridae are important herbivores on coral reefs and are represented at the FGB (and the rest of Florida, the Bahamas and the Caribbean) by three species: *Acanthurus bahianus*, *A. chirurgus* and *A. coeruleus*. Acanthuridae were represented by a mean of 0.93 species/survey at the West Bank in 2004 and 1.92 species/survey at the East Bank.

Shannon-Weiner diversity indices were similar between the East and West Banks in 2005 while indices in 2004 varied from each other and from those of 2005 (Table 7.8). The greatest diversity was calculated for the West Bank in 2004 and the lowest for the East Bank in 2004. Higher sampling effort (larger n) appears to have had a positive effect on diversity and evenness calculations.

*Table 7.8. Fish diversity and evenness values calculated for fish communities surveyed. Source: PBS&J.*

| | 2004 EB | 2004 WB | 2005 EB | 2005 WB |
|---|---|---|---|---|
| Number of Samples (n) | 12 | 27 | 24 | 23 |
| Diversity (log10) | 0.77 | 1.3 | 1.06 | 1.04 |
| Evenness | 0.44 | 0.76 | 0.58 | 0.58 |

Large (visually estimated fork lengths) fish present at the FGB included individuals from the Carangidae, Serranidae, Sphyraenidae and Lutjanidae families. Other families with large individuals included Scaridae, Ballistidae, Pomacanthidae and Kyphosidae. The weighted mean of recorded *Sphyraena barracuda* lengths ranged from 50 cm at the East Bank in 2005 to 88 cm at the West Bank in 2004. *Mycteroperca bonaci* (90 cm-weighted mean length), M. *tigris* (90 cm-weighted mean length), *Lutjanus jocu* (83 cm-weighted mean length) and *M. interstitialis* (50 cm-weighted mean length) were the largest species, aside from *S. barracuda*.

Species in the families Acanthuridae and Scaridae, as well as the Pomacentrid *Microspathodon chrysurus*, can be grouped in an herbivore category comprised of algae-scrapers and -denuders (Steneck, 1988; Pattengill-Semmens and Gittings, 2003). Three species of Acanthuridae and seven species of Scaridae were recorded in the surveys making a total of 11 species in this trophic guild. The mean number of herbivore species per survey ranged from 2.85 at the West Bank in 2004 to 5.07 at the East Bank in 2004. The mean number of herbivore species in 2005 was 3.75 at the East Bank and 3.35 at the West Bank. There was a significant difference (t=3.627, df=37, p=2.0262) in herbivore species richness between the East Bank and the West Bank in 2004, as well as between 2004 and 2005 at the East Bank (t=3.068, df=34, p=2.0322). Mean fish densities of the herbivore group ranged from 5.14 to 10.47/100 m$^2$ at the West Bank in 2005 and the East Bank in 2004, respectively. Densities at the East Bank in 2005 were 6.74/100 m$^2$, and at the West Bank in 2004 were 6.33/100 m$^2$. The only significant difference in mean densities of the herbivore group was found between the East and West Banks in 2004 (t=6.639, df=37, p=8.62 x 10$^{-08}$; Table 7.9). *S. vetula* and *A. coeruleus* were the most frequent species in the herbivore group.

*Table 7.9. Mean densities of fishes (number of fish/100 m$^2$) recorded per survey at the FGB during 2004-2005. Source: PBS&J.*

| Category | 2004 | | 2005 | |
|---|---|---|---|---|
| | East Bank | West Bank | East Bank | West Bank |
| Herbivores | 10.47 | 6.33 | 6.74 | 5.14 |
| Carnivores | 0.57 | 0.46 | 0.38 | 0.66 |
| *Sphyraena barracuda* | 0.85 | 2.81 | 1.91 | 1.51 |
| *Kyophus sectator* | 1.84 | 1.45 | 0.31 | 0.54 |

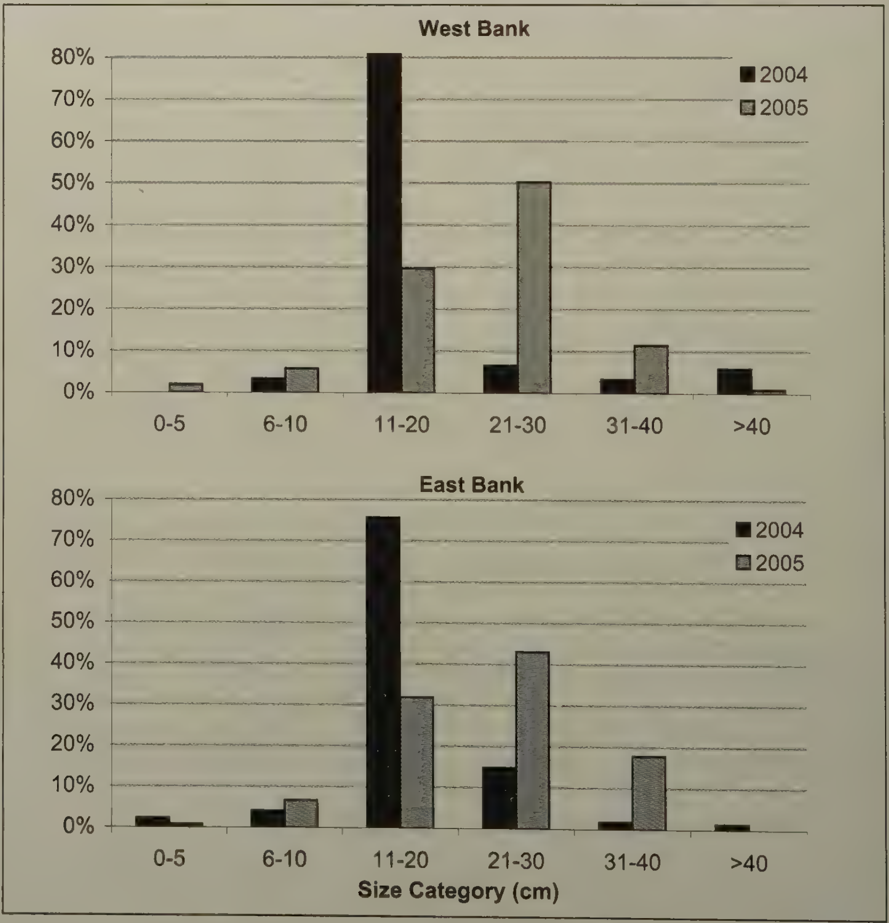


*Figure 7.25. Herbivore size-frequency distributions at WFGB (top) and EFGB (bottom) recorded during 2004 and 2005. Source: Precht et al., in press.*

The size-frequency distributions of herbivorous fishes are normal curves for all years at both banks. The curves for both banks in 2004 are shifted to the lower end of the size ranges and those of West Bank in 2004 shows a more exaggerated (less dispersed) pattern. The curves for 2005 are more evenly dispersed and are shifted more toward the larger sizes (Figure 7.25).

Select species are grouped here as a carnivorous trophic category. These include serranids in the genera *Epinephelus*, *Cephalopholis*, *Mycteroperca* and *Dermatolepis,* as well as all species of lutjanids (Claro and Cantelar Ramos, 2003; Pattengill-Semmens and Gittings, 2003). A total of twelve species were observed in this group: two Lutjanidae and ten Serranidae (three more species than were observed in the 2002-2003 surveys). Although present in large numbers, the serranid *P. furcifer* is not included in the carnivore group. The mean carnivore species richness recorded per survey ranged from 0.63 at the East Bank in 2005 to 1.09 at the West Bank in 2005. Mean species richness recorded in 2004 was 0.74 at the West Bank and 0.83 at the East Bank. No significant differences were found in mean species richness between banks or years. Mean densities of the carnivore group ranged from 0.38/100 $m^2$ at the East Bank in 2005 to 0.66/100 $m^2$ at the West Bank in 2005. Mean densities recorded for 2004 were 0.46/100 $m^2$ at the West Bank and 0.57/100 $m^2$ at the East Bank (Table 7.10). No significant differences were found in mean carnivore densities per survey between years or banks. *M. tigris* and *L. jocu* were among the most frequently recorded species in the carnivore group.

*Table 7.10. Weighted mean sizes (visual estimation of fork length) of the top five largest carnivore species at the East and West Banks in 2004 and 2005. Source: PBS&J.*

| **2004 EAST BANK** | | **2004 WEST BANK** | | **2005 EAST BANK** | | **2005 WEST BANK** | |
|---|---|---|---|---|---|---|---|
| Fish Species | (cm) | Fish Species | (cm) | Fish Species | (cm) | Fish Species | (cm) |
| *Sphyraena barracuda* | 56 | *Mycteroperca tigris* | 90 | *Lutjanus jocu* | 83 | *Mycteroperca bonaci* | 90 |
| *Mycteroperca interstitialis* | 50 | *Serioloa lalandi* | 90 | *Caranx latus* | 60 | *Gymnothorax moringa* | 80 |
| *Caranx lugubris* | 49 | *Sphyraena barracuda* | 88 | *Caranx hippos* | 52 | *Caranx lugubris* | 73 |
| *Canthidermis sufflamen* | 45 | *Caranx latus* | 70 | *Sphyraena barracuda* | 50 | *Sphyraena barracuda* | 66 |
| *Epinephelus adscensionis* | 40 | *Lutjanus griseus* | 55 | *Diodon hystrix* | 50 | *Caranx latus* | 65 |

The size-frequency distributions of the carnivorous fishes were generally non-normal in 2004-2005 and 2002-2003 surveys. The size distribution of carnivorous fish appeared with two peaks for each bank in both years, with the larger peak occurring in the smaller size range at the East Bank in 2004 and in the larger sizes for the other banks and years. The diminished size range was primarily that of the 31-40 cm range and to a lesser degree the 21-30 cm range. The exception was the West Bank in 2004 with the most fishes in the 31-40 cm range. No carnivorous fishes were recorded in the ranges of 0-5 or 6-10 cm at either bank in either year (Figure 7.26).

Analysis of selected species showed some differences in abundances between banks and years. A significant difference (t=2.213, df=48, p=0.03) in *S. barracuda* was found between 2004 and 2005 at the West Bank. The opposite was found during the 2002-2003 surveys, with significant differences occurring between banks but not years. A significant difference (t=2.422, df=34, p=0.02) was found for *Kyphosus sectator/incisor* between 2004 and 2005 at East Bank. During the 2002-2003 surveys, significant differences were found between banks but not between years.

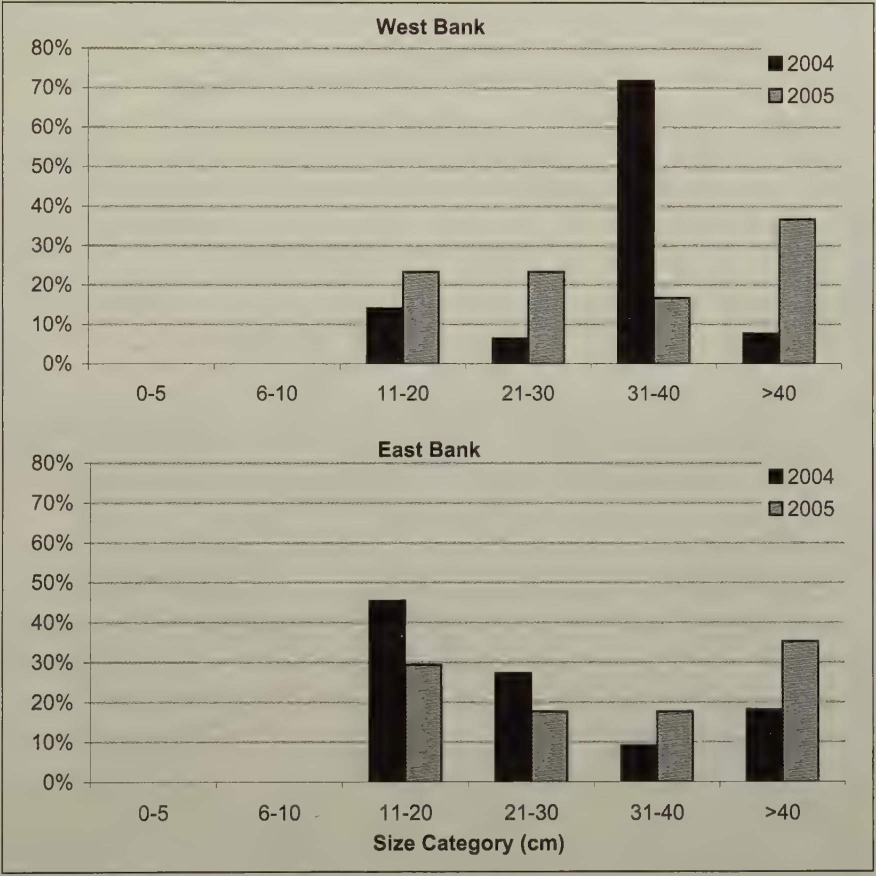


*Figure 7.26. Carnivore size-frequency distributions at West (top) and East Banks (bottom) recorded during 2004 and 2005. Source: Precht et al., in press.*

## Sea Urchin And Lobster Surveys

### *Methods*

Long spined sea urchin (*Diadema antillarum*) surveys were conducted to establish current population levels as a basis for comparison with future observations (Figure 7.27). Surveys were conducted approximately 1.5 hours after sunset using site boundaries as transect lines. Two transects, each 100 x 2 m (200 $m^2$) were surveyed using the same site boundary transect lines as those used for the video transects at each study site. Spiny lobster (*Panulirus argus*) and spotted lobster (*P. guttatus*) surveys were conducted in a similar manner.

*Results and Discussion*

In 2004 at the East Bank, 0.005 individuals/m$^2$ of *D. antillarum* and two *Echinometra lucunter* were documented along the northern and eastern perimeter lines. At the West Bank in 2004, the southern and western lines were monitored for urchins and lobsters, and 0.11 individuals/m$^2$ (44 individuals) of *D. antillarum* were documented. This is a dramatic increase from previous monitoring results. Before the 1984 demise of *D. antillarum* throughout the Caribbean, densities of sea urchins were reported as 0.54-1.63 individuals/m$^2$ (Gittings and Bright, 1987). Although there have been population recoveries in localized areas, population levels throughout the region are still depressed compared to pre-1984 levels (Edmunds and Carpenter, 2001). Two *P. argus* were also documented in 2004.

*Figure 7.27. The long spined sea urchin,* D. antillarum. *Photo: E. Hickerson.*

In 2005 at the East Bank, the northern and eastern perimeter lines were surveyed for urchin and lobster abundance. Urchin density at the East Bank in 2005 was 0.005 individuals/m$^2$. One *P. argus* was documented. At the West Bank, the southern and western lines revealed 0.013 individuals/m$^2$ of *D. antillarum* and one *E. lucunter.*

Similar to the rest of the western Atlantic, results at the FGB from sea urchin and lobster surveys continued to show low population densities at both banks in 2004 and 2005. The low densities reported here are similar to densities reported for the FGB in the past (Precht et al., 2005; Dokken et al., 2003). West Bank 2004 was an anomalous year with 44 individuals documented (0.11 individuals/m$^2$), however the trend did not continue in 2005, when surveyed populations were again depressed (0.013 individuals/m$^2$). Overall, these results do not differ from reports at coral reefs throughout the region.

### *CCMA-BB Characterization of Fish and Benthic Communities at the FGBNMS*

Data on fish species abundance, size, and distribution were collected along a series of timed 25 x 4 m belt transects at 73 sites selected via a stratified random sampling approach based on slope categories of flat and steep. Detailed *in situ* data collection methodologies are accessible by visiting http://ccma.nos.noaa.gov/ecosystems/coralreef/reef_fish/protocols_fgb.html.

*Results and Discussion*

Fish abundance, biomass, richness, and diversity (per 100 m$^2$) are summarized in Table 7.11. The largest disparity between flat and steep strata was observed at the WFGB in both abundance and biomass metrics. In general, species richness, abundance and diversity were relatively similar between the two banks. Biomass was substantially higher on the WFGB.

*Table 7.11. Fish species data collected within timed 25 x 4 m belt transects summarized by strata and overall. * Shannon Diversity Index. Source: CCMA-BB, unpub. data.*

| **LOCATION** | **SLOPE** | **NUMBER OF SURVEYS** | **NUMBER OF INDIVIDUALS (per 100 m$^2$)** | | **BIOMASS (grams per 100 m$^2$)** | | **NUMBER OF SPECIES (per 100 m$^2$)** | | **MEAN DIVERSITY*** | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Mean | (±SE) | Mean | (±SE) | Mean | (±SE) | Mean | (±SE) |
| East Bank | Flat | 44 | 323 | 26 | 18926 | 2904 | 25 | 0.5 | 2.1 | 0.05 |
| | Steep | 5 | 223 | 37 | 19445 | 7011 | 23 | 2.2 | 2.3 | 0.04 |
| | **OVERALL** | 49 | 315 | 22 | 18970 | 2484 | 25 | 0.5 | 2.1 | 0.05 |
| West Bank | Flat | 19 | 259 | 29 | 28657 | 9558 | 27 | 1.0 | 2.2 | 0.07 |
| | Steep | 5 | 497 | 184 | 39148 | 30584 | 27 | 2.1 | 2.1 | 0.19 |
| | **OVERALL** | 24 | 294 | 25 | 30195 | 7618 | 27 | 0.8 | 2.2 | 0.05 |
| All FGBNMS | Flat | 63 | 304 | 16 | 21857 | 2285 | 26 | 0.3 | 2.2 | 0.03 |
| | Steep | 10 | 345 | 48 | 28202 | 8205 | 25 | 1.1 | 2.2 | 0.05 |
| | **OVERALL** | 73 | 308 | 13 | 22518 | 1923 | 26 | 0.3 | 2.2 | 0.03 |

Two federally listed species were observed at FGBNMS in 2006. Nassau grouper (*Epinephelus striatus*) was documented at the FGBNMS for the first time during a scientific investigation, and Goliath grouper (*E. itajara*) was observed for the second time.

Groupers of the genera *Epinephelus*, *Cephalopholis* and *Mycteroperca* were recorded at 66 of the 73 sites surveyed with a total of 232 individuals observed. Furthermore, snapper of the genus *Lutjanus* were recorded at 28 sites with a total of 91 individuals observed. Of particular interest were large aggregations of dog snapper (*L. jocu*).

A large number of juvenile fish were observed among the fields of *Madracis* coral. It is possible that the structure of the *Madracis* coral is being utilized as a nursery area for some species as it offers refuge from predators.

CCMA-BB utilizes the same methodologies to collect fish data at other locations within the U.S. Caribbean. As a point of comparison these data are summarized in Table 7.12. Only sites at or below 60 ft are included in the summary to limit depth as a factor. Both fish density and richness were on the high end but within the range found in the U.S. Caribbean; however, biomass was two and a half times higher than the next closest value. This was due in large part to the presence of sizeable piscivores of the genera *Mycteroperca* and *Dermatolepis* present at FGBNMS.

*Table 7.12. Comparison of fish data between locations in the U.S. Caribbean and the FGBNMS. All data collected within timed 25 x 4 m belt transects. Source: CCMA-BB, unpub. data.*

| **LOCATION** | **NUMBER OF SURVEYS** | **NUMBER OF INDIVIDUALS (per 100 m$^2$)** | | **BIOMASS (grams per 100 m$^2$)** | | **NUMBER OF SPECIES (per 100 m$^2$)** | |
|---|---|---|---|---|---|---|---|
| | | Mean | ±SE | Mean | ±SE | Mean | ±SE |
| FGNMS | 73 | 311.55 | 22.16 | 28945.28 | 7371.55 | 25.67 | 0.46 |
| St. Croix | 66 | 158.74 | 9.56 | 5229.14 | 705.74 | 16.67 | 0.60 |
| St. John | 222 | 370.42 | 21.99 | 8527.49 | 585.29 | 24.76 | 0.43 |
| Puerto Rico | 61 | 117.07 | 10.52 | 3632.92 | 396.11 | 21.82 | 0.88 |

The survey effort to date has primarily focused on the shallower portions of the Sanctuary with little to no quantitative information on the deeper water environments or an understanding of how they are connected to the coral caps. Beginning in 2008, the FGBNMS in collaboration with NCCOS/CCMA-BB will begin to incorporate the deeper water regions into the overall survey design utilizing a combination of ROV and drop camera technologies.

## Benthic Habitat Mapping

As reported in the 2005 report, the FGBNMS has been updating benthic characterization maps, through the use of high resolution bathymetric maps and ROV surveys. The first level biological characterization maps are presented in Figures 7.28, 7.29 and 7.30.

Rezak et al. (1985) developed a classification and characterization scheme for biological communities associated with the reefs and banks of the northwestern Gulf of Mexico. This classification structure was the culmination of a large body of work on the FGB (Bright and Pequegnat, 1974; Bright et al., 1985) and other reefs and banks in the area. Subsequent investigations have demonstrated the accuracy and usefulness of this classification framework. However, based on recent information, we propose some minor modifications to and reorganization of the classification scheme proposed by Rezak et al. (1985).

Coral reefs and coral communities form a mosaic of biological habitats at the FGB and other reefs and banks of the northwestern Gulf of Mexico. In addition to the

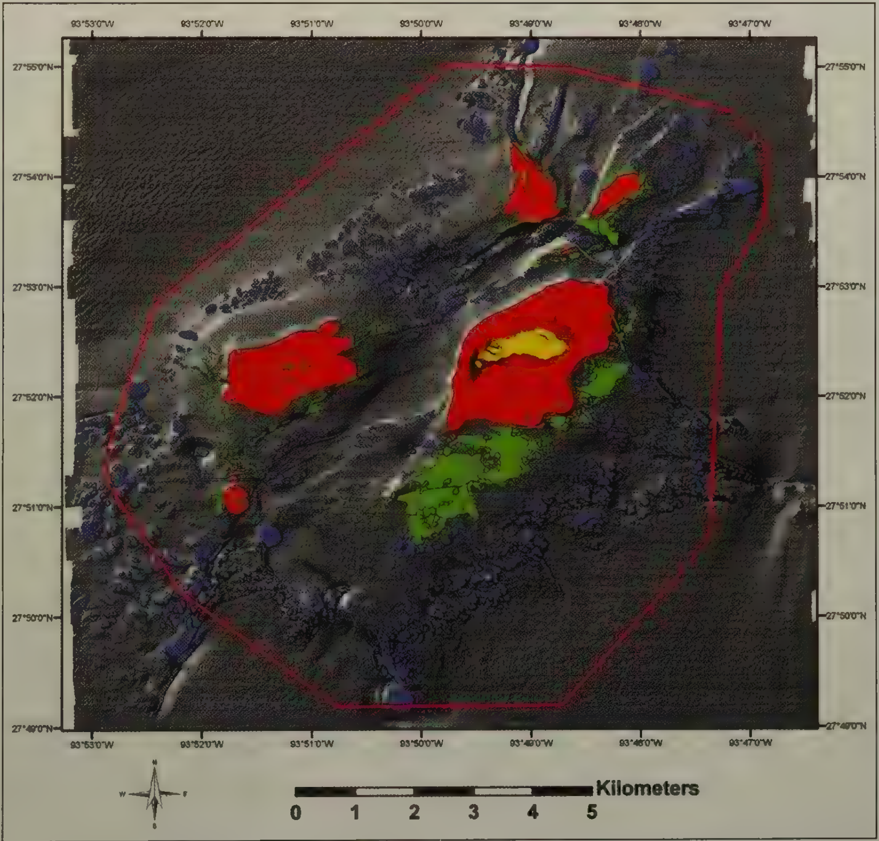


*Figure 7.28. WFGB biological habitats. Please see the next page for this map's legend. Source: FGBNMS. Map: D. Weaver.*

**Legend**

- 🟥 FGBNMS boundary
- 🟨 coral reef zone
- 🟪 coral community zone
- coralline algal zones
  - 🟩 coralline algal reefs
  - 🟥 algal nodules
- 🟦 deep coral zone

well-developed hermatypic coral reefs that cap the shallowest portions of the EFGB and WFGB, there are a variety of other reef habitats that occur in association with many other topographic features in the area. All of these habitats could be considered as part of the coral reef ecosystem of the northern Gulf of Mexico and include coralline algal reefs and deep reef communities. We propose a classification hierarchy composed of biological zones. Within each zone there are multiple habitat types.

The first major biological zone is the "Coral Reef." The coral cap of the EFGB and WFGB exemplifies this zone. The Coral Reef Zone proposed here includes the "*Diploria-Montastraea-Porites*" zone, the "*Madracis* and Leafy Algae" zone and the "*Stephanocoenia-Millepora*" zones as described by Rezak et al. (1985). We propose that these classifications are sub-components of the coral reef zone. Major habitats within this zone are described by the dominant coral species that characterize the assemblage. The primary habitat of the coral reef zone of the FGB is the *Montastraea* habitat. Rezak et al. (1985) called this community the *Diploria-Montastraea-Porites* zone, but this is somewhat misleading in that the brain coral *Diploria* is not the dominant component of the species assemblage. Members of the genus *Montastraea* account for over 65% of the coral species encountered, while *Diploria* accounts for about 11%. Therefore it is more appropriate that the primary habitat within the coral reef zone be referred to as the *Montastraea* habitat. Other habitats within the coral reef zone include those typified by *Madracis* (*Madracis* and Leafy Algae zone of Rezak et al., 1985), *Stephanocoenia* (*Stephanocoenia-Millepora* of Rezak et al., 1985) and coral sand (composed of reef derived sediments). The *Montastraea* habitat is the primary hermatypic reef community of the FGB, and includes at least 23 species of stony corals. This habitat is interspersed by

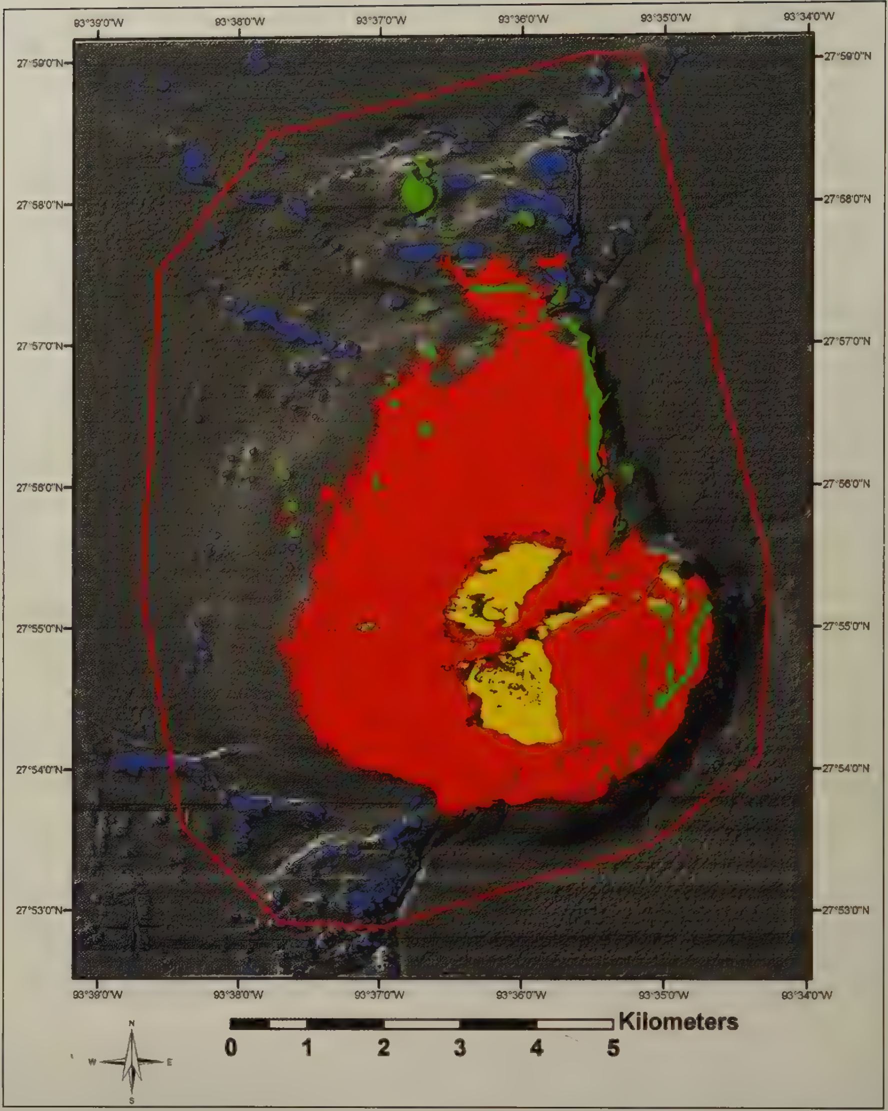

93°39'0"W
93°38'0"W
93°37'0"W
93°36'0"W
93°35'0"W
93°34'0"W
27°59'0"N
27°58'0"N
27°57'0"N
27°56'0"N
27°55'0"N
27°54'0"N
27°53'0"N
N
W
E
S
Kilometers
0
1
2
3
4
5

Figure 7.29. EFGB biological habitats. Source: FGBNMS. Map: D. Weaver.

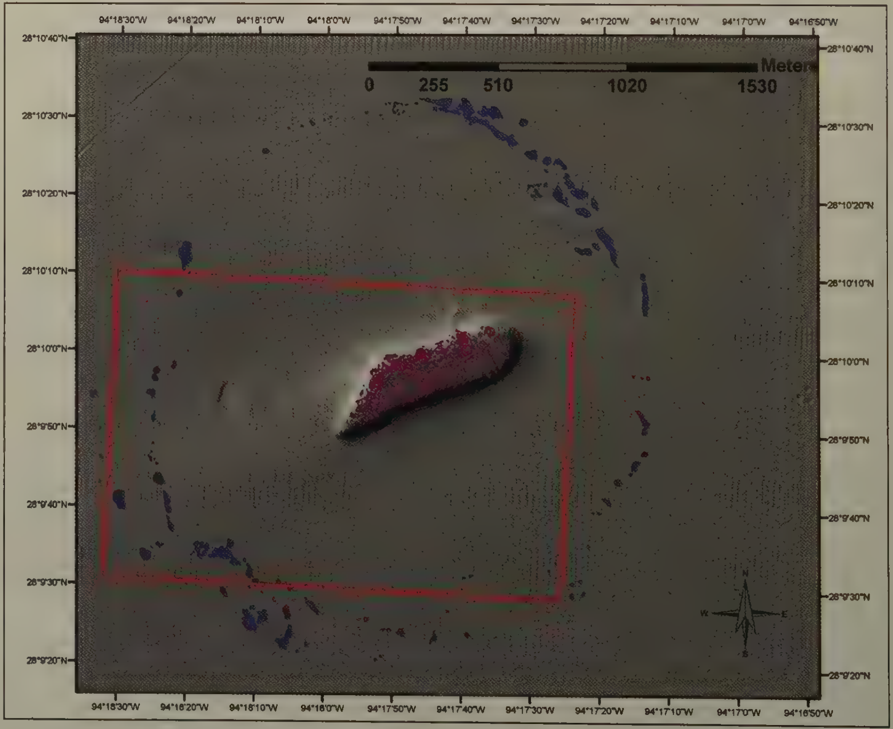

94°18'30"W
94°18'20"W
94°18'10"W
94°18'0"W
94°17'50"W
94°17'40"W
94°17'30"W
94°17'20"W
94°17'10"W
94°17'0"W
94°16'50"W
28°10'40"N
28°10'30"N
28°10'20"N
28°10'10"N
28°10'0"N
28°9'50"N
28°9'40"N
28°9'30"N
28°9'20"N
Meters
0
255
510
1020
1530
N
W
E
S

Figure 7.30. Stetson Bank biological habitats. Source: FGBNMS. Map: D. Weaver

sand channels comprised of coral sand (coral debris with molluscan and algal components). The *Madracis* habitat occurs on the peripheral parts of the primary reef structure in depths ranging from 28 to 44 m, where large knolls characterized by almost monospecific stands of the small branching coral *Madracis mirabilis* occur. The *Stephanocoenia* habitat is a lower diversity coral community occurring in water depths primarily below 36 m. While dominated by the blushing star coral (*Stephanocoenia intersepta*), other species such as *Millepora alcicornis*, *Colpophyllia natans*, *Agaricia* spp., *Mussa angulosa* and *Scolymia* spp. are also encountered.

The second biological zone we call the "Coral Community Zone." This zone is comprised of areas that, while not considered to be "true" coral reefs, do contain hermatypic coral species at low densities, or are characterized by other coral reef associated organisms, such as the hydrozoan *Millepora* spp. (fire coral), sponges and macroalgae. Coral communities are found in depth ranges similar to those that contain coral reefs (18 to 50 m, but other environmental factors have not allowed full development of coral reefs to occur. The "Coral Community" includes the "*Millepora*-Sponge" zone described by Rezak et al. (1985), and also includes some other coral associated assemblages. The most distinctive habitat type in this zone is the *Millepora*-sponge community that characterizes the shallowest peaks of the mid-shelf reefs at Stetson and Sonnier Banks. The fire coral, *Millepora* spp., can account for up to 30% of the benthic cover on the pinnacles of Stetson Bank (Bernhardt, 2000). In addition to fire coral, sponges comprise up to an additional 30% of the substrate. The Coral Community Zone also includes habitats that are characterized by scattered occurrences of stony corals or fire coral at relatively low densities. This habitat, called the low-density coral habitat, also includes a mix of other components including leafy algae, coralline algae, sponges and anemones. Habitats within the Coral Community Zone can also be characterized by algae or sponges when they dominate a particular area.

The next primary area is the "Coralline Algae Zone" zone, characterized by crustose coralline algae that actively produce carbonate substrate, including rhodoliths, or algal nodules. The Coralline Algae Zone is consistent with that proposed as the "Algal-Sponge Zone" by Rezak et al. (1985), but includes additional habitat such as rocky outcrops. This zone is the largest reef-building zone area in the FGB extending from 45 to over 90 m in depth. Algal nodules, or rhodoliths, are formed by species of coralline algae that lay down successive, concentric layers of carbonate around an initial "nucleus" (such as a rock fragment) to form irregular spheres of 1–20 cm in size. Between 50-75 m, the nodules can cover 60-90% of the bottom (Minnery et al., 1985) and can often occupy 100% of the sea floor in some areas. Primary species include the coralline algae *Lithothamnium* sp., the squamariacean *Peyssonnelia* sp. and the encrusting foraminiferan *Gypsina plana*. Several species of hermatypic corals are scattered throughout the Algal Nodule Zone, and can be locally abundant, including saucer shaped specimens of *Agaricia* spp. and *Helioseris cucullata*. Leafy algae and sponges, most notably the toxic sponge *Neofibularia nolitangere*, are also common in this habitat. The Coralline Algae Zone also includes deepwater coralline algal reefs, which are typically low-relief (1-2 m high), flat-topped rocky outcrops, ridges and patch reefs. While coralline algae is the dominant benthic group on these reefs, the rocky outcrops provide habitat for a variety of gorgonians, antipatharians, sponges and other organisms. This zone corresponds with the area called "Partly Drowned Reefs" by Bright and Pequegnat (1974) and Bright et al. (1985). Since the concept of "drowned reef" implies certain geological origins and temporal history, this terminology is not used here in relation to present-day biological communities. In fact, Bright et al. (1985) defined "partly drowned reefs" as reef structures below the depths of hermatypic corals, but within a depth range favoring crustose coralline algae. This is consistent with the concept as used in the present classification.

The final reef-associated community is the "Deep Coral Zone". The deep coral zone is consistent with what Bright et al. (1985) called the "Drowned Reef Zone". This zone occurs in water depths below that which support active photosynthesis by coralline algae (90 m and greater). Solitary corals and deepwater branching corals, such as *Madrepora* and *Oculina* are also found in this zone. The Deep Coral Zone is characterized by a diverse assemblage of antipatharian and gorgonian corals, crinoids, bryozoans, sponges, azooxanthellate branching corals and small, solitary hard corals. It includes both low and high relief rock outcroppings of various origins. Rock outcrops are often highly eroded and lack coralline algal growth. Reef outcrops may be covered with a thin layer of silt in areas subject to frequent resuspension of sediments. The area of high sediment resuspension and turbid water was termed the "Nepheloid" zone by Bright et al. (1985) and Rezak et al. (1985). Since this terminology refers to a physical oceanographic condition and not a biological classification, it is not used here. Habitats within this zone include those characterized by dominant organisms of antipatharians, gorgonians, crinoids or coral, or mixtures of these component groups.

This effort is the first step in comprehensively characterizing the FGBNMS. Future efforts, in partnership with CCMA-BB, will focus on refining the level of characterization through further mapping, higher level bathymetric analysis, ROV and drop camera surveys. This project will be initiated in 2008.

### *Overall Condition and Summary of Analytical Results*

The overall health of the reefs of the EFGB and WFGB continues to be described as stable, supporting over 50% live coral cover comprised of primarily robust and massive species. *Montastraea franksi*, as part of the *Montastraea annularis* species complex, dominates the community, with *Diploria strigosa* also providing substantial cover. The stability of the system is evidenced by the continued high coral cover, and the ability to recover following hurricanes and bleaching events. Algae appear to play a balanced role in the reef habitat and do not appear threatening to the coral component. Other than during hurricane events, water quality continues to be consistently good.

## CURRENT CONSERVATION MANAGEMENT ACTIVITIES

Regulations governing the FGBNMS are authorized under the National Marine Sanctuaries Act, as amended, 16 U.S.C. 1431, and are contained within the Code of Federal Regulations 15 C.F.R. 922 (Subparts A, E, and L), available on the Internet at http://www.sanctuaries.nos.noaa.gov/oms/omsflower/omsflowerpubdoc.html. They are designed to protect the sensitive coral reef features of the Sanctuary. The regulations prohibit anchoring of any vessel within the Sanctuary; mooring of any vessel greater than 100 feet on a Sanctuary mooring buoy; oil and gas exploration and development within a designated no activity zone (almost the entire Sanctuary); injuring or taking coral and other marine organisms; using fishing gear other than traditional hook and line; discharging or depositing any substances or materials; altering the seabed; building or abandoning any structures; and using explosives or electrical charges.

In 2001, the International Maritime Organization designated the FGBNMS as the world's first international no-anchor zone. This designation enhances the protection and awareness of the site by providing guidance and regulations at an international level.

In 2005, the FGBNMS helped the Gulf of Mexico Fisheries Management Council (GOMFMC) recommend sites in the northwestern Gulf of Mexico as Habitat Areas of Particular Concern (HAPC). Although, in general, this designation does not carry any regulations that would protect the sites, a subgroup of the HAPC's were designated as Coral Essential Fish Habitat (EFH) Areas under the HAPC designation. This designation does carry regulations, including prohibiting anchoring, prohibiting trawling, bottom longlines, and trap/pot gear. EFGB and WFGB were already Coral EFH areas. The GOMFMC added Stetson Bank, McGrail Bank and a portion of Pulley's Ridge (Florida) under the Coral EFH designation.

The FGBNMS research team have developed regional identification posters for deepwater biota (50-180 m), including fishes, sponges, black corals, gorgonians, algae and invertebrates. These may be useful for researchers conducting projects in these depth ranges, and lessen the need to collect samples for identification. Copies of these posters can be downloaded from http://www.flowergarden.noaa.gov/document_library/sci_documents.html.

The FGBNMS is currently undergoing a management plan review. Issues that have been identified through a public scoping process conducted by the FGBNMS and the Sanctuary Advisory Committee include impacts from visitor use, harvesting impacts from fishing, boundary expansion needs, impacts of pollutant discharge, enforcement and education/outreach. Working groups have been created for each issue, and the groups are holding workshops to assist in information gathering and move the decision making process forward.

## OVERALL CONCLUSIONS AND RECOMMENDATIONS

The major deleterious impacts of 2005, including coral disease, major hurricanes, and coral bleaching clearly demonstrated that in spite of its remote location, the coral communities of the FGBNMS are susceptible to major environmental perturbations. There is no sign that these impacts will be any less severe in years to come. Importantly, small amounts of tissue are lost during each event, and while they may not be measurable from year to year, on a reef-wide scale, the cumulative effects may be detectable over time.

We may not currently have the tools or techniques to fight coral disease or bleaching or be able to divert the path of a major hurricane, but there are human activities that are manageable, and that's where the effort should be placed to attempt to slow down the negative forces that are wearing down the resilience of coral reefs and associated habitats.

The coral reef ecosystem at the FGB continues to thrive, despite its location in the middle of one of the largest oil and gas fields in the world. Each year, Sanctuary staff review dozens of new requests for pipeline or platform installation within the MMS four-mile regulatory zone. One unresolved concern associated with oil and gas activities is the large quantities of contaminated water, or "produced water" that is generated during offshore oil platform operations. The effects of produced water on coral reef ecosystems are unknown and represent a significant knowledge gap that needs to be addressed in response to the expansion of oil and gas activities in the region.

Other substantial knowledge gaps exist, in part due to the difficulty of accessing this relatively remote location. While distance from shore may lessen some of the impacts attributed to recreational use, it also hampers monitoring of human activities, research with respect to recreational use of the area by divers and fishers, and enforcement of Sanctuary regulations. While some data on visitor use can be attained by a variety of remote methods such as overflights, satellite imagery, and radar systems, the need for the Sanctuary to increase on-site observation, management, and enforcement has not been met. However, in response to this need the FGBNMS has constructed and implemented a vessel – an 83 ft catamaran, the R/V *Manta*, which will greatly enhance enforcement, management, research and education capabilities beginning in summer 2008.

The location and depth of the FGB also makes the logistics involved in monitoring activities difficult and expensive, which limits the frequency of sampling and the total area able to be surveyed during data collection. Under the current long-term monitoring methods, sampling points are limited to a 100 $m^2$ area in the shallowest part of the coral caps, which represents a fraction of the total area of the banks. Limitations in sampling frequency and spatial distribution of survey effort restrict scientists' analytical power to measure change with a sufficient level of confidence, especially when trying to account for adjacent reefs or banks. The addition of the CCMA-BB collaborative project has greatly enhanced our ability to assess the reef in its entirety because the approach used complements the fixed-site surveys. It is critical to continue this component of stratified random surveys throughout the coral cap and expand these efforts into the deeper waters of the Sanctuary. There is currently no funding to incorporate this project on a long-term basis.

Despite these limitations, both the LTM Project results and those of the joint FGBNMS and CCMA-BB study indicate that the EFGB and WFGB reefs are relatively pristine when compared to other Caribbean reef systems. Budget constraints have precluded the analysis of Stetson Bank monitoring data to date, but analysis of existing data is a priority for increasing management capability. Anecdotal and photographic observations made at Stetson Bank are noted (e.g., 2005 bleaching event), but cannot be acted upon without quantitative evidence.

The observations indicating that FGBNMS is an important spawning area for several species of grouper warrants further investigation and highlights the importance of considering a no-take marine reserve to protect the biodiversity of this region. It is clear that the reefs of the FGBNMS are biologically and ecologically connected with the numerous other reefs and banks found in the northwestern Gulf of Mexico that are unprotected. Both of these issues will be addressed during the FGBNMS Management Plan Review.

The coral reef ecosystem of the FGBNMS is in good or excellent condition. It is crucial that the status of this resource be maintained. In a world of declining coral reef health, this site can be used as a standard for comparison to other Caribbean coral reef systems and may function as a source of recruits for neighboring regions.

## REFERENCES

Bernhardt, S.P. 2000. Photographic Monitoring of Benthic Biota at Stetson Bank. Thesis. Texas A&M University. College Station, TX.

Bohnsack, J.A. and S.P. Bannerot. 1986. A stationary visual census technique for quantitatively assessing community structure of coral reef fishes. NOAA Technical Report NMFS 41. Seattle, WA. 15 pp.

Bright, T.J. and L.H. Pequegnat (eds.). 1974. Biota of the West Flower Garden Bank. Gulf Publishing Company, Book Division. Houston, TX. 435 pp.

Bright, T.J., D.W. McGrail, R. Rezak, G.S. Boland, and A.R. Trippet. 1985. The Flower Gardens: A compendium of information. OCS Report MMS 85-0024. Minerals Management Service, Gulf of Mexico OCS Region Office, U.S. Department of the Interior. New Orleans, LA. 103 pp. http://www.gomr.mms.gov/homepg/regulate/environ/techsumm/rec_pubs.html.

Bruckner, A. Office of Habitat Conservation, NOAA National Marine Fisheries Service. Silver Spring, MD. Personal communication.

Claro, R. and K. Cantelar Ramos. 2003. Rapid assessment of coral communities of Maria la Gorda, southeast Ensendada de Corrientes, Cuba (Part 2: Reef fishes). Atoll Res. Bull. 496: 279-293.

DeDitton, R.B. and C.E. Thailing. 2001. The Economic Impacts of Sport Divers Using the Flower Garden Banks National Marine Sanctuary. Department of Wildlife and Fisheries Sciences, Texas A&M University, TX. 11 pp. http://lutra.tamu.edu/hdlab/publications.htm.

Dennis, G.D. and T.J. Bright. 1988. Reef fish assemblages on hard banks in the northwestern Gulf of Mexico. Bull. Mar. Sci. 43(2): 280-307.

Deslarzes, K.J.P. (ed.). 1998. The Flower Garden Banks (Northwest Gulf of Mexico): Environmental Characteristics and Human Interaction. OCS Report MMS 98-0010. Minerals Management Service, Gulf of Mexico OCS Region, U.S. Department of the Interior. New Orleans, LA. 100 pp. http://www.gomr.mms.gov/homepg/regulate/environ/techsumm/rec_pubs.html.

Deslarzes, K.J.P. and A. Lugo-Fernández. 2007. Influence of terrigenous runoff on offshore coral reefs: An example from the Flower Garden Banks, Gulf of Mexico. pp. 126-160. In: R.B. Aronson (ed.). Geological approaches to coral reef ecology. Springer. New York, NY. 422 pp.

Dokken, Q.R., I.R. MacDonald, J.W. Tunnell Jr., C.R. Beaver, G.S. Boland, and D.K. Hagman. 1999. Long-Term Monitoring at the East and West Flower Garden Banks, 1996-1997. OCS Study MMS99-0005. Minerals Management Service, Gulf of Mexico OCS Region, U.S. Department of the Interior. New Orleans, LA. 122 pp. http://www.gomr.mms.gov/homepg/regulate/environ/techsumm/rec_pubs.html.

Dokken, Q.R., I.R. MacDonald, J.W. Tunnell Jr., T. Wade, K. Withers, S.J. Dilworth, T.W. Bates, C.R. Beaver, and C.M. Rigaud. 2003. Long-Term Monitoring at the East and West Flower Garden Banks, 1998-2001: Final Report. OCS Report MMS 2003-031. U.S. Department of the Interior, Minerals Management Service, Gulf of Mexico OCS Region. New Orleans, LA. 90 pp. http://www.gomr.mms.gov/homepg/regulate/environ/techsumm/rec_pubs.html.

Dunton, K. Marine Science Institute, The University of Texas. Austin, TX. Personal communication.

Edmunds, P.J. and R.C. Carpenter. 2001. Recovery of *Diadema antillarum* reduces macroalgal cover and increases abundance of juvenile corals on a Caribbean reef. pp. 5067-5071. In: Proceedings of the National Academy of Sciences 98(9). 552 pp.

Fenner, D. 2001. Biogeography of Three Caribbean Corals (Scleractinia) and the invasion of *Tubastraea coccinea* into the Gulf of Mexico. Bull. Mar. Sci. 69(3): 1175-1189.

Fenner, D. and K. Banks. 2004. Orange Cup Coral *Tubastraea coccinea* invades Florida and the Flower Garden Banks, Northwestern Gulf of Mexico. Coral Reefs 23: 505-507.

Gardner, J. V., L.A. Mayer, J.E. Hughes Clarke, and A. Kleiner. 1998. High-Resolution Multibeam Bathymetry of East and West Flower Gardens and Stetson Banks, Gulf of Mexico. Gulf Mex. Sci. 16(2): 128.

Gittings, S.R. 1998. Monitoring at the Flower Gardens: history and status. pp. 623-630. In: Proceedings of the 17th Information Transfer Meeting. Minerals Management Service, Gulf of Mexico OCS Region, U.S. Department of the Interior. New Orleans, LA. 710 pp.

Gittings, S.R. and T.J. Bright. 1987. Mass mortality of *Diadema antillarum* at the Flower Garden banks, northwest Gulf of Mexico: effect on algae and coral cover (abstract). Benthic Ecology Meetings, Raleigh, NC.

Gittings, S.R., G.S. Boland, K.J.P. Deslarzes, D.K. Hagman, and B.S. Holland. 1992. Long-term monitoring at the East and West Flower Garden Banks. Final Rept. OCS Report MMS 92-006. Minerals Management Service, Gulf of Mexico OCS Region, U.S. Department of the Interior. New Orleans, LA. 206 pp. http://www.gomr.mms.gov/homepg/regulate/environ/techsumm/rec_pubs.html.

Gittings, S.R., T.J. Bright, and D.K. Hagman. 1993. Protection and monitoring of reefs on the Flower Garden Banks, 1972-1992. pp. 181-187. In: R.N. Ginsburg (ed.). Proceedings of the Coloquium on Global Aspects of Coral Reefs: Healths, Hazards and History. University of Miami, FL. 440 pp.

Graham, R. Wildlife Conservation Society, Belize. Personal communication.

Hagman, D.K. and S.R. Gittings. 1992. Coral bleaching on high latitude reefs at the Flower Garden Banks, NW Gulf of Mexico. pp. 38-43. In: R.H. Richmond (ed.). Proceedings of the 7th International Coral Reef Symposium, Vol. 1. Guam, Micronesia. 650 pp.

Minnery, G.A., R. Rezak, and T.J. Bright. 1985. Depth zonation and growth form of crustose coralline algae: Flower Garden Banks, Northwestern Gulf of Mexico. pp. 237-246. In: D.F. Toomey and M.H. Nitecki (eds.). Paleoalgology: Contemporary Research and Applications. Springer-Verlag, Berlin. 376 pp.

Parsons-Hubbard, K. Oberlin College, OH. Personal communication.

Pattengill, C.V. 1998. The Structure and Persistence of Reef Fish Assemblages of the Flower Garden Banks National Marine Sanctuary. Ph.D. Dissertation. Texas A&M University, TX. 164 pp.

Pattengill-Semmes, C.V. and S.R. Gittings. 2003. A Rapid Assessment of the Flower Garden Banks National Marine Sanctuary (Stony Corals, Algae and Fishes). pp. 500-511. In: J.C. Lang (ed.). Status of Coral Reefs in the Western Atlantic: Results of Initial Surveys, Atlantic and gulf Rapid Reef Assessment (AGRRA) Program. Atoll Res. Bull. 496. 630 pp.

Precht, W.F., R.B. Aronson, K.J.P. Deslarzes, M.L. Robbart, T.J.T. Murdoch, A. Gelber, D.J. Evans, B. Gearheart, and B. Zimmer, 2005. Long-term monitoring at the East and West Flower Garden Banks, 2002-2003: Final report. OCS Study MMS 2006-035. Minerals Management Service, Gulf of Mexico OCS Region, U.S. Department of the Interior. New Orleans, LA. 193 pp. http://www.gomr.mms.gov/homepg/regulate/environ/techsumm/rec_pubs.html.

Precht, W.F., R.B. Aronson, K.J.P. Deslarzes, M.L. Robbart, D.J. Evans, B. Zimmer, and L. Duncan. 2008a. Long-Term Monitoring at the East and West Flower Garden Banks,2004-2005: Final Report. Minerals Management Service, Gulf of Mexico OCS Region, U.S. Department of the Interior. New Orleans, Louisiana.

Precht, W.F., R.B. Aronson, K.J.P. Deslarzes, M.L. Robbart, B. Zimmer, L. Duncan. 2008b. Post Hurricane Assessment at the East Flower Garden Bank Long-Term Monitoring Site November 2005: Final Report. Minerals Management Service, Gulf of Mexico OCS Region, U.S. Department of the Interior. New Orleans, LA.

Rezak, R., T.J. Bright, and D.W. McGrail. 1985. Reefs and Banks of the Northwestern Gulf of Mexico: Their Geological, Biological, and Physical Dynamics. John Wiley and Sons, New York. 259 pp.

Schmahl, G.P. and E.L. Hickerson. 2006. McGrail Bank, a deep tropical coral reef community in the northwestern Gulf of Mexico. pp. 1124-1130. In: Y. Suzuki, T. Nakamori, M. Hidaka, H. Kayanne, B.E. Casareto, K. Nadaoka, H. Yamano, and M. Tsuchiya (eds.). Proceedings of the 10th International Coral Reef Symposium. Okinawa, Japan. 1950 pp.

Sinclair, J. Minerals Management Service, Gulf of Mexico OCS Region, U.S. Department of the Interior. New Orleans, LA. Personal communication.

Stenneck, R.S. 1988. Herbivory on coral reef: A synthesis. pp. 37-49. In: J.H. Choat, D. Barnes, MA. Borowitzka, J.C. Coll, P.J.Davies, P. Flood, B.G. Hatcher, D. Hopley, P.A. Hutchings, D. Kinsey, G.R. Orme, M. Pichon, P.F. Sale, P. Sammarco, C.C. Wallace, C. Wilkinson, E. Wolanski, and O. Bellwood (eds.). Proceedings of the 6th International Coral Reef Symposium, Vol. 1. Townsville, Australia. 285 pp.

U.S. Department of the Interior, Minerals Management Service. 1996. Long-term monitoring at the East and West Flower Garden Banks. MMS 96-0046. Prepared by Continental Shelf Assoc. Inc. Minerals Management Service, Gulf of Mexico OCS Region, U.S. Department of the Interior. New Orleans, LA. 77 pp. http://www.gomr.mms.gov/homepg/regulate/environ/techsumm/rec_pubs.html.

Weaver, D.C, E.L. Hickerson, and G.P. Schmahl. 2006. Deep reef fish surveys by submersible on Alderdice, McGrail, and Sonnier Banks in the Northwestern Gulf of Mexico. In: J.C. Taylor (ed.). Emerging technologies for reef fisheries research and management. NOAA Professional Paper NMFS 5. 116 pp.

# The State of Coral Reef Ecosystems of the Main Hawaiian Islands

Alan Friedlander[1,2], Greta Aeby[3], Russell Brainard[4], Eric Brown[5], Kathy Chaston[6], Athline Clark[7], Petra McGowan[7], Tony Montgomery[7], William Walsh[7], Ivor Williams[7] and Wendy Wiltse[8]

Contributors: Jacob Asher[4,11], Seema Balwani[4], Eric Co[9], Eric DeCarlo[10], Paul Jokiel[3], Jean Kenyon[4,11], Jason Helyer[4,11], Cindy Hunter[12], Joyce Miller[4,11], Carrie Morshige [13], John Rooney[4,11], Hudson Slay[8], Robert Schroeder[4,11], Heather Spalding[14], Lisa Wedding[3] and Thierry Work[15]

## INTRODUCTION AND SETTING

The main Hawaiian Islands (MHI) form the southern part of the Hawaiian Archipelago, which is located in the middle of the North Pacific Subtropical Gyre, centered at about 28°N (Figure 8.1). The MHI consist of eight high volcanic islands that range in age from active lava flows on the east side of the Big Island (Hawaii Island) to seven million-year-old Kauai (Figure 8.2). Owing to its location in the middle of the Pacific Ocean, Hawaii's coral reefs are exposed to large open ocean swells and strong tradewinds that have a major impact on the structure of the coral reefs and result in distinctive communities that are sculpted by these dynamic natural processes. Circulation is primarily from east to west and intensifies southward, however, in the lee of the islands, surface currents driven by wind combine with large-scale ocean currents to yield more complicated flow patterns such as eddies (Flament et al., 1996). The average surface water temperature around Oahu is 24°C (75°F) in winter and 27 °C (81°F) in summer.

The geographic isolation of Hawaii has resulted in some of the highest endemism of any tropical marine ecosystem on earth (Kay and Palumbi, 1987; Jokiel, 1987; Randall, 1998). Some of these endemics are dominant components of the coral reef community, resulting in a unique ecosystem that has extremely high conservation value (DeMartini and Friedlander, 2004; Maragos et al., 2004). With species loss in the sea accelerating, the irreplaceability of these species makes Hawaii an important biodiversity hotspot.

Coral reefs were important to the ancient Hawaiians for subsistence, culture and survival. Today these reefs provide commercial, recreational and subsistence fishing opportunities, create world famous surfing and diving locations, and are vital to Hawaii's approximately $800 million a year marine tourism industry. The economic value of Hawaii's coral reefs was estimated at US$10 billion with direct economic benefits of $360 million per year in 2002 (Cesar and van Beukering, 2004). Despite their economic significance, reefs near urbanized areas have experienced increasing stress from human and land-based impacts due to ever-increasing population pressures.

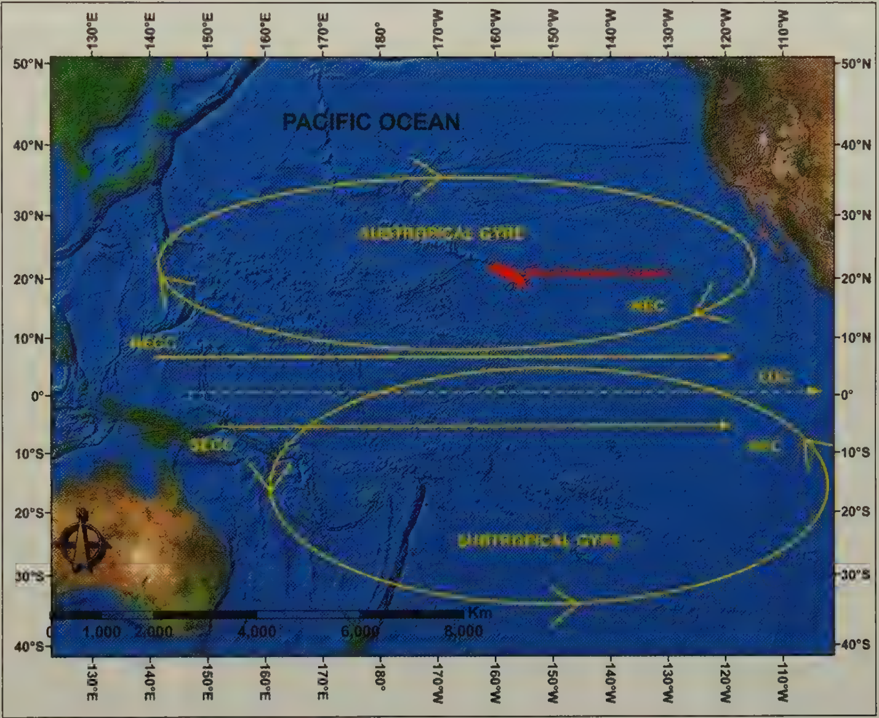


*Figure 8.1. Topographic map showing the location of the MHI and the major ocean currents in the region: North Equatorial Current (NEC), South Equatorial Current (SEC), North Equatorial Counter Current (NECC), South Equatorial Counter Current (SECC), Equatorial Under Current (EUC). Source: PIFSC-CRED.*

---

1. NOAA/ NOS/ NCCOS/ Center for Coastal Monitoring and Assessment, Biogeography Branch
2. The Oceanic Institute
3. University of Hawaii, Hawaii Institute of Marine Biology
4. NOAA/ NMFS/ Pacific Islands Fishery Science Center, Coral Reef Ecosystem Division
5. National Park Service
6. University of Hawaii, College of Tropical Agriculture and Human Resources
7. Hawaii Department of Land and Natural Resources, Division of Aquatic Resources
8. Environmental Protection Agency
9. The Nature Conservancy of Hawaii
10. University of Hawaii, Oceanography
11. Joint Institute for Marine and Atmospheric Research
12. University of Hawaii, Biology
13. Hawaii Sea Grant Program
14. University of Hawaii, Botany
15. U.S. Geological Survey

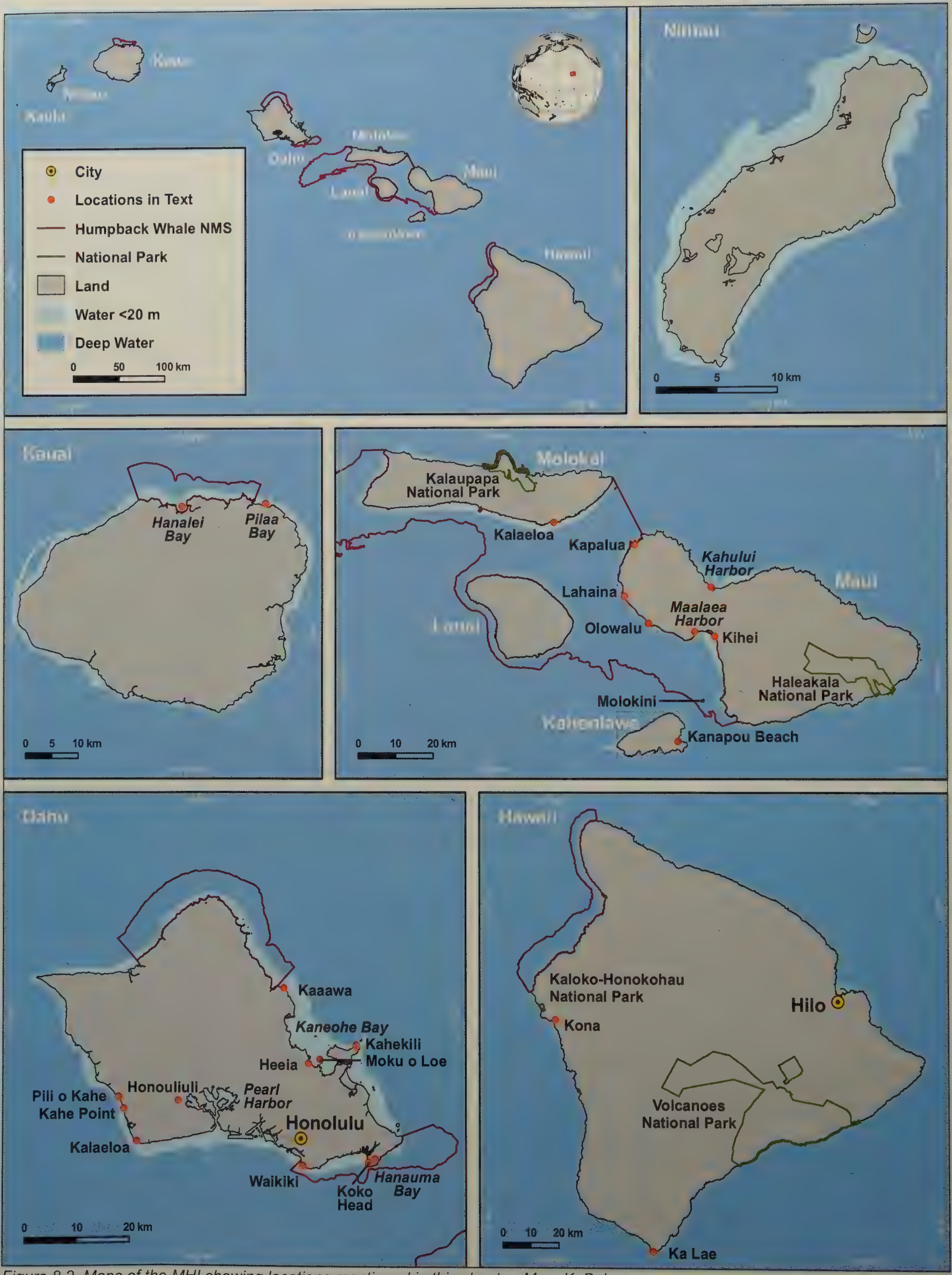

Kauai
Niihau
Kaula
Oahu
Molokai
Lanai
Maui
Kahoolawe
Hawaii
City
Locations in Text
Humpback Whale NMS
National Park
Land
Water <20 m
Deep Water
0 50 100 km
Niihau
0 5 10 km
Kauai
Hanalei Bay
Pilaa Bay
0 5 10 km
Molokai
Kalaupapa National Park
Kalaeloa
Kapalua
Kahului Harbor
Maui
Lahaina
Lanai
Olowalu
Maalaea Harbor
Kihei
Haleakala National Park
Molokini
Kahoolawe
Kanapou Beach
0 10 20 km
Oahu
Kaaawa
Kaneohe Bay
Kahekili
Moku o Loe
Heeia
Honouliuli
Pearl Harbor
Pili o Kahe
Kahe Point
Honolulu
Kalaeloa
Waikiki
Koko Head
Hanauma Bay
0 10 20 km
Hawaii
Kaloko-Honokohau National Park
Kona
Hilo
Volcanoes National Park
Ka Lae
0 10 20 km

*Figure 8.2. Maps of the MHI showing locations mentioned in this chapter. Map: K. Buja.*

## ENVIRONMENTAL AND ANTHROPOGENIC STRESSORS

### Climate Change and Coral Bleaching

As a result of recent bleaching events and increased ocean warming trends, climate change has become an important issue in Hawaii. Climate change is expected to influence water temperatures, ocean pH and sea level with related changes in available coral reef habitat, wave climate and coastal shorelines (U.S. EPA, 1998). Hawaiian waters show a trend of increasing temperature over the past several decades that are consistent with observations in other coral reef areas of the world (Figure 8.3, Coles and Brown, 2003). The average annual sea surface temperatures (SSTs) in Hawaii have increased 0.8°C since 1956, and rising water temperatures are expected to increase the frequency and severity of bleaching events (Jokiel and Coles, 1990).

To date, there have only been three documented bleaching events within the Hawaiian archipelago. The first documented large-scale coral bleaching occurred on Oahu during late summer of 1996. This bleaching event was triggered by a prolonged regional positive oceanic sea surface temperature anomaly that developed offshore during the time of the annual summer temperature maximum. High solar energy input and low winds further elevated inshore water temperatures by 1-2°C in reef areas with restricted water circulation (e.g., Kaneohe Bay, Oahu) and in areas where mesoscale eddies retain water masses close to shore for prolonged periods of time. The other two bleaching events occurred on the reefs of the Northwestern Hawaiian Islands (NWHI). In 2002, mass coral bleaching occurred predominantly on the back reefs of the three northernmost atolls (Pearl and Hermes, Midway, Kure; Aeby et al., 2003; Kenyon et al., 2006a). Over 60% of the corals bleached in these shallow, back reef environments. In 2004, another although less severe, event occurred in the NWHI (Kenyon and Brainard, 2006). Please see the NWHI chapter of this report for details.

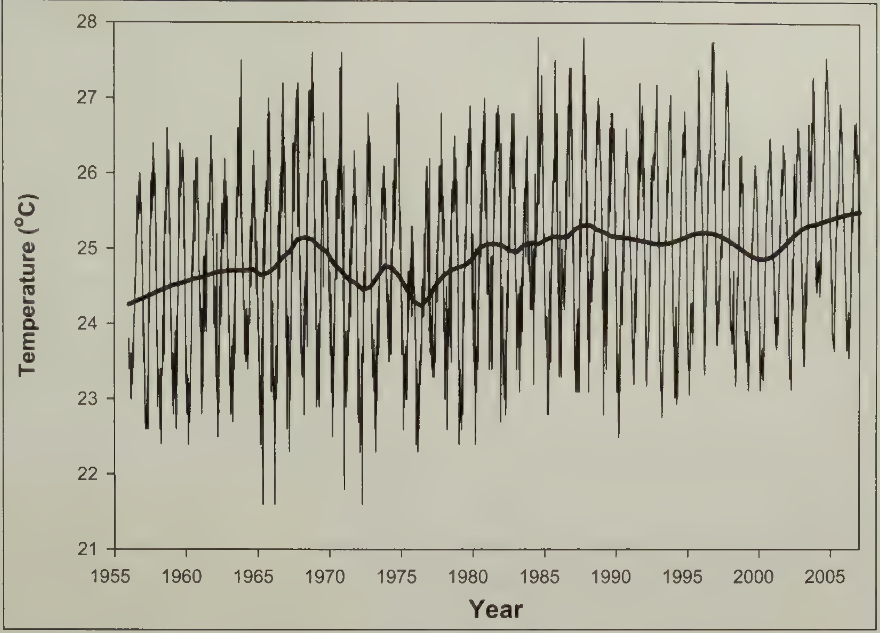


*Figure 8.3. Weekly averaged NOAA temperature series taken at Koko Head, Oahu (21°17'N, 157°41'W) and weekly IGOSS-NMC data series that overlapped temporarily. Data sets were merged and smoothed using a LOWESS averaging function. Source: Jokiel and Brown (2004) with extended data from http://ingrid.ldeo.columbia.edu/.*

### Diseases

Baseline disease studies were initiated on Oahu in 2004 and Maui in 2005, and multi-agency research cruises in 2005 and 2006 facilitated surveys at all eight main Hawaiian Islands. Analysis of 2004 and 2005 surveys (n=78), revealed eight coral diseases from the three major coral genera (*Porites, Montipora, Pocillopora*). Disease was widespread but occurred at low levels. Differences were found among disease states with some diseases such as *Porites* trematodiasis being very common while other diseases had a limited distribution (Figure 8.4, Aeby et al., unpub. data). Oahu, Maui and the Big Island had the highest occurrence of disease, as well as the highest prevalence (proportion of corals surveyed which had signs of disease; Table 8.1; Aeby et al., unpub data). Disease assessment is now a component of the state-wide coral reef monitoring program and a set of underwater disease identification cards have recently been produced.

Two coral diseases of potential concern are *Porites* growth anomalies (Figure 8.5) and

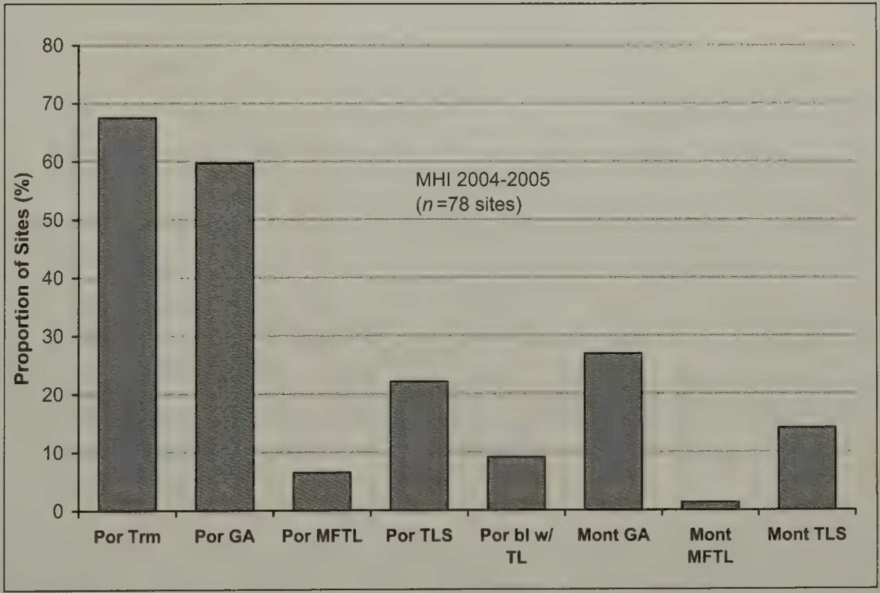


*Figure 8.4. Frequency of occurrence of different coral diseases within the MHI. Por=*Porites*, Mont=*Montipora*, TRM= trematodiasis, TLS=tissue loss syndrome, GA=growth anomaly, MFTL=multifocal tissue loss, WS=white syndrome, Source: Aeby et al., unpub. data.*

*Montipora* white syndrome (Figure 8.5). *Porites* growth anomalies are more widespread in the MHI (59.7% of sites surveyed) compared to the reefs of the NWHI (4.9% of sites; Aeby, 2006; Aeby et al., unpub. data). *Montipora* white syndrome, first found in Kaneohe Bay in 2004, causes acute tissue loss and has now been documented throughout the MHI. Prevalence of this disease is approximately four times higher in Kaneohe Bay (average prevalence=0.27 + 0.08% SE) than in the other main islands (avgerage prevalence=0.06 + 0.02% SE; Aeby et al., unpub. data).

*Table 8.1. Differences in disease levels among islands within the MHI. Disease surveys conducted in 2004 and 2005. Source: Aeby et al., unpub. data.*

| **Island** | **# Sites Surveyed** | **Depth (ft)** | **Avg. Coral Cover (%) (± SE)** | **Frequency of Disease Occurance (%)** | **Avg. Disease Prevalence (± SE)** |
|---|---|---|---|---|---|
| Hawaii | 19 | 24-50 | 29.2 ± 3.2% | 100.0 | 1.20 ± 0.44% |
| Maui | 11 | 7-50 | 41.1 ± 7.5% | 100.0 | 1.36 ± 0.37% |
| Oahu | 27 | 5-60 | 23.6 ± 3.9% | 100.0 | 1.03 ± 0.25% |
| Kauai | 12 | 21-56 | 7.5 ± 1.8% | 83.3 | 0.39 ± 0.21% |
| Niihau | 6 | 30-50 | <1 (<1) | 16.7 | 0.02 ± 0.02% |
| Lehua | 3 | 38-50 | <1 (<1) | 33.3 | 0.02 ± 0.02% |
| **Total** | **78** | | | | |

The endangered Hawaiian green sea turtle is affected by fibropapillomatosis (FP), a disease that causes external and internal tumors. Recent evidence suggests herpes virus as a probable cause or co-factor of FP (Quackenbush et al., 1998). This disease has been present in turtle populations in Hawaii since the early 1950s (Balazs and Pooley, 1991), but ongoing surveys on Molokai indicate that the prevalence of FP has been declining steadily for the past 5-8 years (Balaz, PIFSC data).

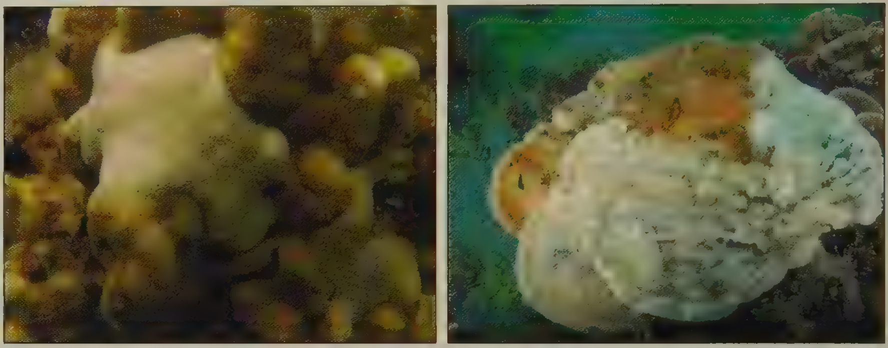


*Figure 8.5.* Porites lobata *with growth anomaly (left).* Montipora capitata *with white syndrome (right). Photos: G. Aeby.*

A number of diseases have been observed in reef fishes. Two endemic butterflyfishes (*Chaetodon multicinctus* and *C. milliaris*) in Maui had a high prevalence of skin tumors possibly caused by suspected contaminants (Okihiro, 1988). Other studies have examined the possibility of disease transmission between the introduced blue-lined snapper (*Lutjanus kasmira*) and co-occurring native goatfish species (*Mulloidicthys* spp.). Surveys of four different species of goatfishes from Maui and Oahu revealed infections with a protozoan similar to that found in blue-lined snappers with prevalence ranging from 25 to 90%. In contrast, prevalence of the putative bacterium in goatfish is very low (<1%, Work and Aeby, unpub. data).

The first documented disease event in Hawaiian marine algae occurred in West Maui (Spalding, unpub. data). *Halimeda kanaloana* is an endemic, calcified green alga forming expansive meadows over soft, sandy substrate. In July 2006, a 50 $m^2$ area (approximately) of the meadow began to die (Figure 8.6). Individual plants began to turn yellow and shed their segments, eventually resulting in plant death. Current studies are tracking the spread and survival of *Halimeda* plants in this diseased area, and monitoring for possible recovery.

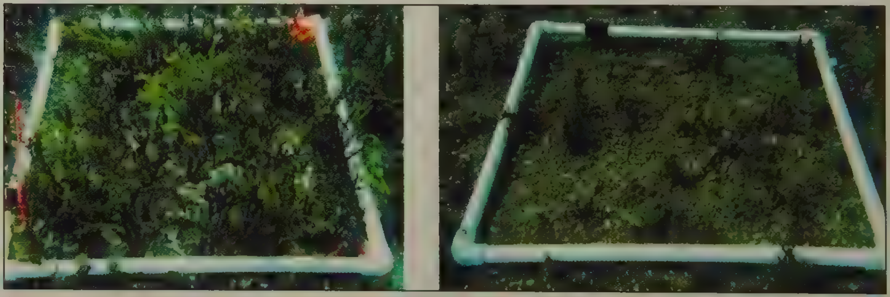


*Figure 8.6.* Halimeda kanaloana *densities in healthy (left) and diseased (right) areas. The white quadrat is 0.25 $m^2$. The diseased area is covered with a thick layer of dead white* Halimeda *segments. Photo: H. Spalding.*

## Tropical Storms

A unique set of biogeographical factors and physiological tolerances structure Hawaiian reefs and limit community assemblages to a relatively few hearty species. Breaking waves from surf generated by Pacific storms is typically the most important factor structuring exposed reef communities throughout the MHI (Dollar and Grigg, 2004; Jokiel et al., 2004). Several exceptions exist: areas influenced by recruitment events (Coles and Brown, 2007) and sheltered embayments which are impacted by anthropogenic activities (Dollar and Grigg, 2004). Recent evidence from reef cores indicates that in the last 11,000 years the only substantial accretion presently taking place in Hawaii occurs in sheltered embayments or inside barrier reefs that are protected from storm wave impact (Rooney et al., 2004). These sheltered areas, however, make up less than 5% of the coastal areas of the MHI.

In general, the Hawaiian archipelago's wave climatology is characterized by large (>5 m), long period (15-25 seconds) surface gravity waves during the winter months and relatively small (1-3 m), short period (7-11 seconds) waves during the summer months (Figure 8.7). Seasonally large waves are due to the combination of an active Aleutian Low, the large area of the North Pacific and the Hawaiian Islands geographic location. Easterly trade winds associated with the North Pacific Subtropical High are the primary source of shorter period and smaller wave heights during summer months. Long period, larger wave events (3-4 m) occur during summer; but are typically ephemeral due to the extended travel distance of wave trains from their source, the Southern Ocean, to the Hawaiian Islands.

In recent decades only two major hurricanes (Hurricane Iwa, 1982; Hurricane Iniki, 1992) have struck the islands. Some reefs were reshaped by Hurricane Iniki (Figure 8.8). Since 2005, Tropical Storms Kenneth (2005), Jova (2005), Daniel (2006) and Fabio (2006) have come relatively close to the main Hawaiian Islands, impacting local rain and wind patterns but not causing significant damage or loss (Figure 8.9).

Recovery from storm events varies by site and is often driven by recruitment events (Coles and Brown, 2007). Recent evidence from consistent long-term sampling on Oahu indicates that coral cover at sites in close proximity (100 m -1 km) respond differently to storm activity and cycle independently of each other (Figure 8.10). This pattern appears to be driven by recruitment pulses of 10-12 years for *Pocillopora meandrina* and 15 or more years for *Porites lobata* that occurred at different time periods within each site.

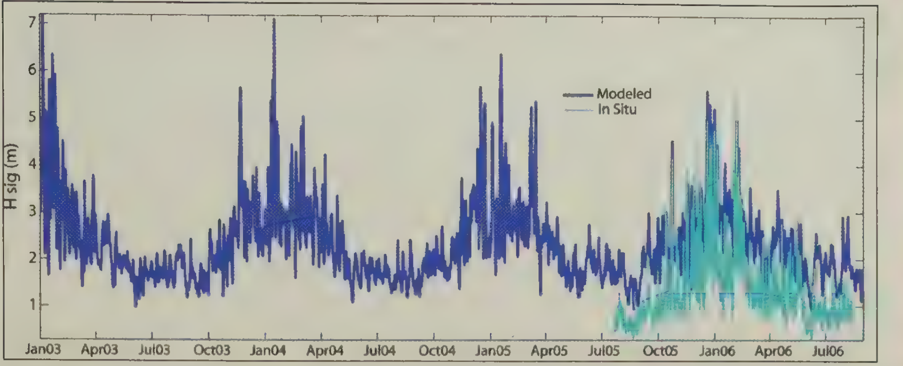


*Figure 8.7. In situ and Wave Watch III significant wave height (m) data from Mana Reef (west Kauai) from January 2003 to September 2006. Note that the in situ data are collected near shore and contains wave shoaling, whereas the modeled data are for the open ocean. Source: PIFSC-CRED.*

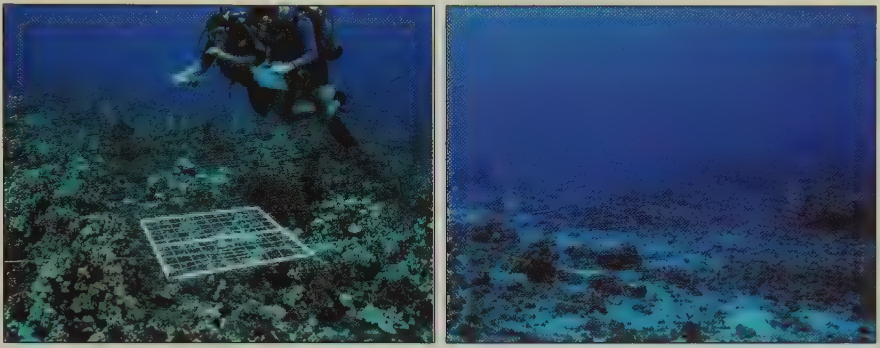


*Figure 8.8. Reef structure at Puamana, Maui prior to (left) and after (right) Hurricane Iniki in 1992. Photos: E. Brown.*

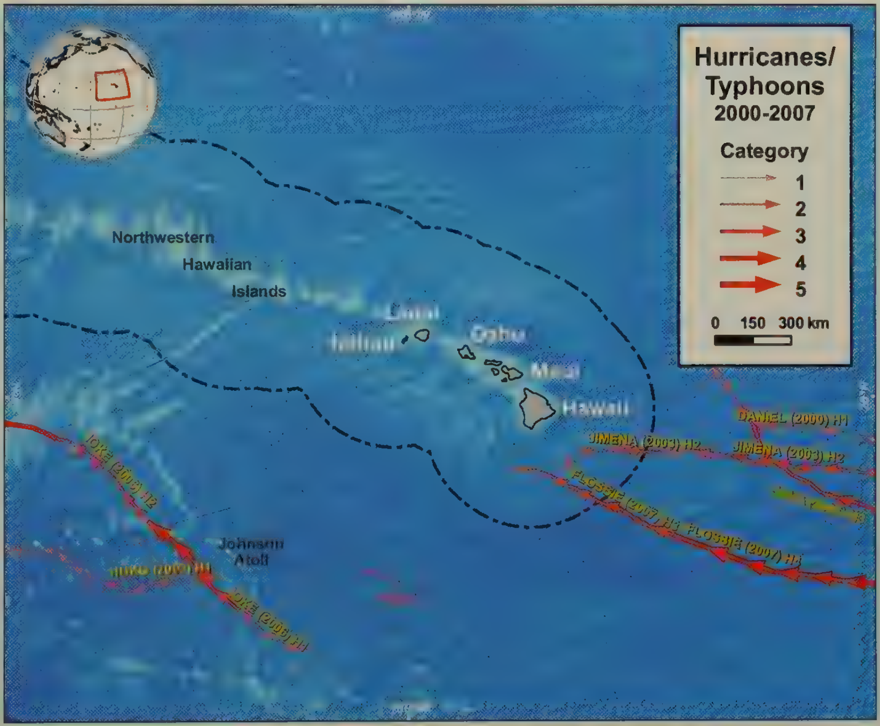


*Figure 8.9. A map showing the paths and intensities of tropical storms passing near the MHI from 2000-2007. Map: K. Buja. Source: http://weather.unisys.com/hurricane/.*

During El Niño Southern Oscillation (ENSO) events in the MHI, warmer sea surface temperatures in the equatorial Pacific cause the subtropical high to shift closer to the islands, forcing trade winds to subside and suppressing Kona storms and fronts near Hawaii (Figure 8.11). As a result, leeward areas that depend on winter season rain from these storms tend to experience drought. Conversely, during neutral periods and La Niñas, this high-pressure center is absent, enabling Kona storms and fronts to form or migrate into their vicinity (Rooney and Fletcher, 2005). ENSO is a naturally occurring phenomenon, however, there is uncertainty regarding how global warming and the associated climate changes will impact the frequency and/or magnitude of this cycle, and how that will in turn affect coral reef ecosystems.

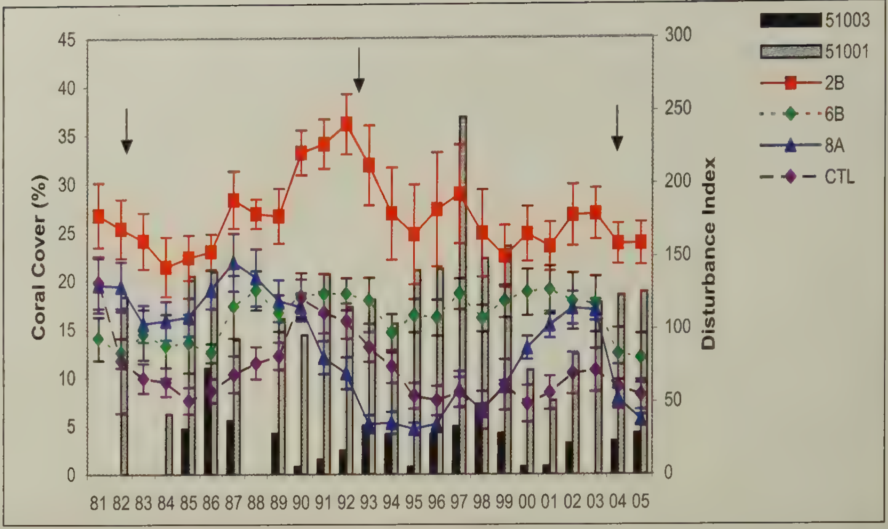


*Figure 8.10. Yearly total coral cover from 1981-2005 at coral monitoring sites (line plots), and disturbance indices calculated for wave data from NOAA Buoys 51001(gray bars) and 51003 (black bars) for all data available from 1981 to 2005. Arrows indicate Hurricanes Iwa (1982) and Iniki (1992) and major local storm runoff (2004). Errors bars are ± 1 SE of the mean. Source: Coles and Brown, 2007.*

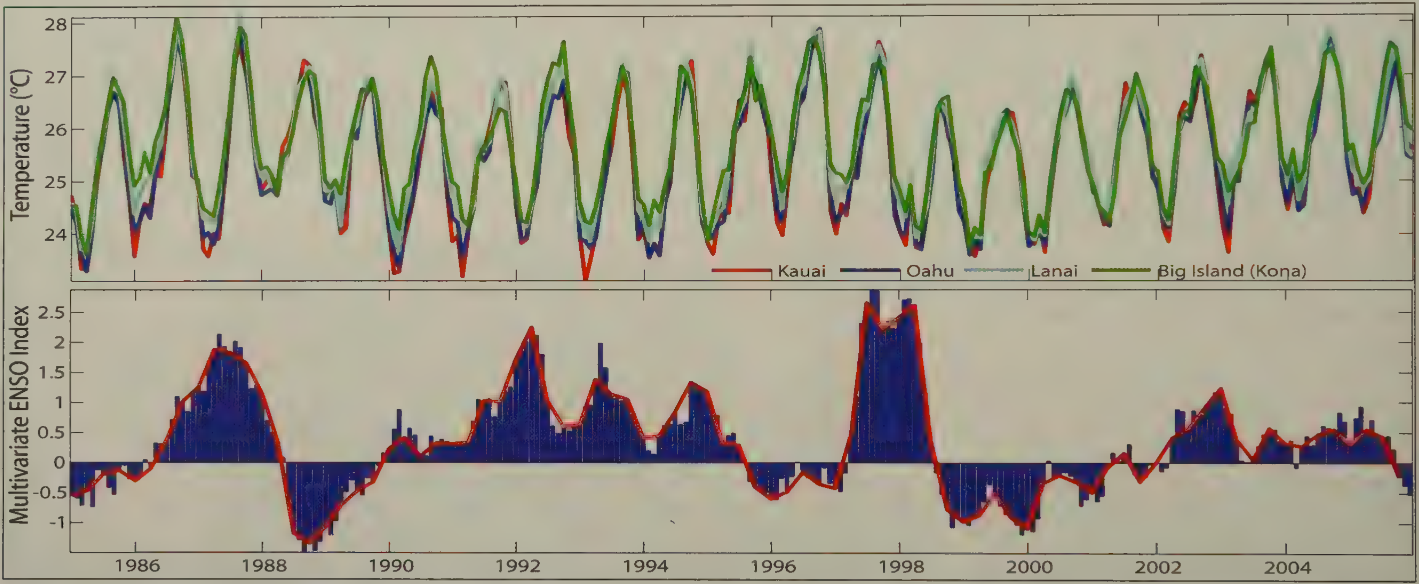


*Figure 8.11. Relationship between NOAA Pathfinder SSTs (top) and ENSO Multivariate Index (MEI; bottom) for the MHI from 1985 to 2006. Positive (negative) values of the MEI indicate El Niño (La Niña) conditions Source: PIFSC-CRED, unpub. data.*

## Coastal Development and Runoff

Hawaii's coastlines continue to be developed for a variety of land uses. Agricultural lands that were once primarily used to grow sugarcane and pineapple are being converted to residential and resort uses across the state. Total acreage of sugarcane decreased almost 50% from 1995 to 2005 with 33,167 ha (81,957 acres) and 16,246 ha (40,145 acres) estimated respectively (State of Hawaii Data Book, 2005). Many of Hawaii's low-lying coastal areas were once wetlands and flood plains before being altered for agriculture and development. More sediment is delivered to nearshore waters as coastal areas are developed, floodplains filled, storm drains constructed and streams channelized (Figure 8.12). Detailed land-use change data are not available for Hawaii, although baseline land cover data were collected in 2000 through the NOAA Coastal Change Analysis Program. The NOAA Pacific Science Center is currently developing a GIS layer of impervious surfaces in Oahu, which is scheduled to be completed by the end of 2007.

Harbor facilities on all the MHI are being improved to accommodate new large cruise ships, an inter-island car/cargo ferry, large container ships, increasing demand for commercial and recreational facilities, and the need to improve harbor entrance safety. In Kahului Harbor on Maui, the proposed expansion of pier space to accommodate additional large ships may displace outrigger canoe teams and surfers. At Maalaea Harbor on Maui, a $10 million expansion of berthing facilities and reconfiguration of the entrance channel has been planned for 40 years. The preferred design is controversial because it will eliminate 6 ha of coral reef and impact a surf site, while providing over 100 new berths for recreational and commercial boats. A new Supplemental Draft Environmental Impact Statement is expected to be released in 2007 to advance this controversial project.

## Coastal Pollution

### *Point Sources*

Seven major wastewater treatment plants discharge to the coastal ocean in Hawaii (Table 8.2). All but two of these discharge through deepwater outfalls (>40 m) where there is little potential for impact to coral reefs.

Although deepwater outfalls do not appear to impact the shallow reefs of Hawaii's coastal waters, spills of untreated or poorly treated wastewater are a public health concern for bathers and surfers. A very large spill of more than 184.3 million liters (48.7 million gallons) of untreated wastewater occurred on March 24, 2006 into the Ala Wai canal near Waikiki. The spill continued for over five days and beaches at Waikiki were posted with warning signs for weeks. The number of sewage spills reported by the city and county of Honolulu to U.S. Environmental Protection Agency (EPA) during 2000-2004 was high, ranging from 200-300 spills per year. Most of the reported spills did not discharge to surface waters but were contained on land. Enforcement actions and lawsuits related to sewage spills on Oahu are currently pending.

In addition to discharges from wastewater treatment facilities, individual and general National Pollutant Discharge Elimination System (NPDES) permits are also required for storm water. Major NPDES storm water permits provide coverage for the municipal separate storm sewer system of the City and County of Honolulu, and state highways within the City and County of Honolulu under Hawaii Department of Transportation jurisdiction. Permits also cover airports and harbors throughout the state. The General Permit authorizing discharges of storm water associated with construction activity requires a Notice of Intent be filed with Department of Health prior to the initiation of land disturbance activities greater than one acre (Figure 8.13). The General Permit requires, among other things, that a construction best management practices plan be developed and implemented to minimize erosion of soil and discharge of other pollutants into state waters.

In recent years, erosion from coastal construction sites has damaged coral reefs on the Big Island and on Kauai, resulting in costly lawsuits and enforcement actions. In the Kauai case, a $7.5 million settlement was announced in March 2006 for Clean Water Act violations that resulted in sediment damage to a home, beach and coral reef at Pilaa Bay. The violations involved grading a coastal property and filling streams without the required Clean Water Act permits. Storm water erosion control measures, as required by the permits, may have prevented damage from sediment-laden runoff. This is the largest

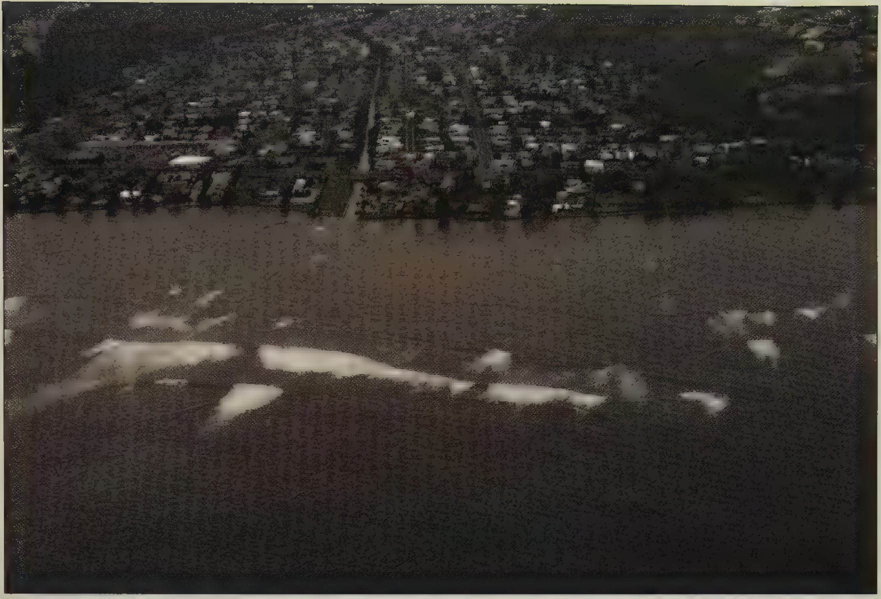


Figure 8.12. Coastal runoff in Maunalua Bay, Oahu. Photo: The Nature Conservancy.

Table 8.2. Wastewater treatment plants that discharge to Hawaii's coastal waters. Source: U.S. EPA.

| | DESIGN FLOW (millions of gallons per day) | LEVEL OF TREATMENT |
|---|---|---|
| **Deepwater Discharges(>40 m)** | | |
| Sand Island, Oahu | 82 | Advanced primary |
| Honouliuli, Oahu | 38 | Advanced primary |
| Waianae, Oahu | 5 | Secondary |
| Kailua, Oahu | 15 | Secondary |
| Hilo, Hawaii | 5 | Secondary |
| **Shallow Water Discharges (<40 m)** | | |
| East Honolulu, Oahu | 3.9 | Secondary |
| Ft. Kamehameha, Oahu | 13 | Secondary |
| Wailua, Kauai | 1.5 | Secondary |

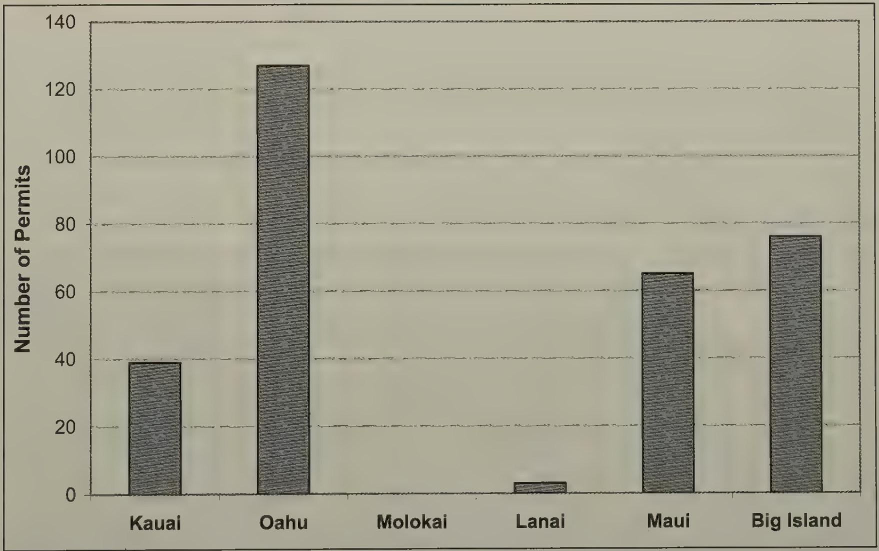


Figure 8.13. Number of NPDES Construction General Permits granted from 2005-2006. Source: HIDOH.

stormwater settlement for violations at a single site, by a single landowner in the U.S. It involved EPA, the Department of Justice, Hawaii Department of Health, Kauai County and Earth Justice. The settlement calls for payment of $2.2 million in penalties and $5.3 million to prevent erosion and restore damaged streams at the construction site. In a related state enforcement action, the Hawaii Board of Land and Natural Resources fined the property owner an additional $4 million for natural resources damages to the beach and coral reef.

*Nonpoint Sources*

Sediment is probably the leading land based pollutant causing alteration of reef community structure in the MHI (Figure 8.14). Several major sources of erosion have been removed or reduced, which will likely lower the potential for negative effects in the future. Examples include the closure of large agricultural plantations, cessation of live fire training on the island of Kahoolawe, and culling programs for feral ungulates on the islands of Lanai and Molokai.

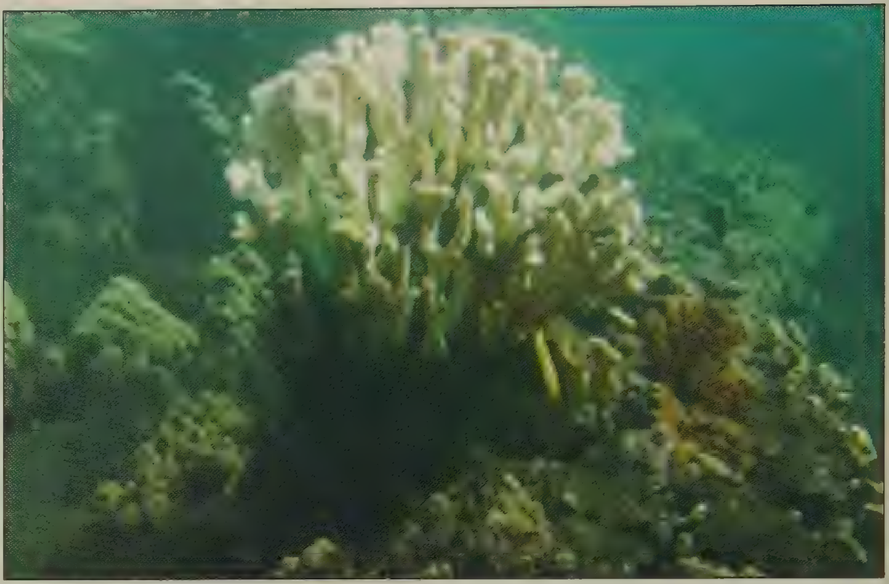


*Figure 8.14. Sediment covering the reef at North Kohala, Hawaii. Photo: B. Walsh.*

In many areas of Hawaii, nearshore water chemistry is a mixture of oceanic water and freshwater emanating from both submarine groundwater discharge at or near the shoreline and surface water runoff. Hawaii's groundwater and surface water discharge are equivalent to about 20% of rainfall (Yuen and Associates, 1992), except on Kauai, which has a higher rate due to greater overall rainfall. Groundwater in Hawaii typically contains two to three orders of magnitude higher concentrations of dissolved nitrogen and phosphorus than seawater. Thus, groundwater nutrients are an important factor of nearshore marine water chemistry. The groundwater nitrogen load reflects natural background and anthropogenic sources from wastewater and fertilizers. Calculations using values from U.S. Geological Survey (USGS) groundwater models show that ambient groundwater contributes about 1,800 tons of nitrogen annually to the nearshore ocean along the west coast of the Big Island.

On neighbor islands, most of the sewage treatment plants discharge secondary treated wastewater into the ground through 15-60 m deep injection wells. In some cases, a portion of the effluent is reused for irrigation, providing additional opportunity for nutrient and particulate removal. Plumes from these injection wells have generally not been identified and traced. However, a recent tracer study on Maui identified the plume from the Kihei injection well down-gradient from the injection well between the treatment plant and the shore (Hunt, 2007). Models predict that the wastewater plumes mix with groundwater and discharge to the ocean fairly close to the shoreline in water less than 30 m deep.

Cesspools are a potentially harmful source of untreated wastewater, and Hawaii has an estimated 100,000 cesspools, more than any other state in both relative and absolute terms (EPA, unpub. data). The effects of nutrient and pathogen seepage on coral reefs is not known. Hawaii Department of Health (HIDOH) has issued new administrative rules that either ban or severely restrict the use of cesspools throughout the state. New cesspools are completely banned on the islands of Oahu and Kauai. On the islands of Maui, Molokai and Hawaii, new cesspools for individual homes only are allowed in certain areas. Through support from the Hawaii Coastal Zone Management Program, the University of Hawaii Water Resources Research Center is working on a project to provide information to promote the effective use of traditional, as well as innovative on-site wastewater treatment systems in rural and urban settings and to ensure that the technology is protective of water quality and the environment.

While there is no state-wide nutrient budget to assess the total magnitude of anthropogenic nutrient subsidies to groundwater, Soicher and Peterson (1997) developed a comparison for a relatively small region of West Maui. In this region, 91.3% of the nitrogen delivery to the ocean is associated with anthropogenic activities. It is of interest to note that since this estimate was compiled, sugarcane and pineapple farming have largely ceased. While there have been no documented impacts to the reefs in West Maui as a result of the additional nutrients, this coastline is known to have nuisance algal blooms.

Toxic pollutants are seldom measured in Hawaii's marine waters. In southern Kaneohe Bay, Hunter et al. (1995) reported elevated concentrations of lead, copper, chromium and zinc in oyster tissues near stream mouths. High levels of dieldrin and chlordane were also found in oyster tissues at some sites. In the Hanalei River and Estuary, the USGS reported trace levels of dieldrin, chlordane and DDE in fish and clams (Orazio et al., 2003). No polyaromatic hydrocarbons (PAHs) were detected in the water and only trace levels were found in sediments at one station. All organic contaminants were below EPA toxicity levels and in most cases were below limits of detection.

## Tourism and Recreation

Tourism is Hawaii's primary industry, and visitor arrivals have shown a dramatic increase since 1970 (Figure 8.15). 2005 was a record-breaking year for Hawaii's visitor sector in terms of arrivals, visitor days and tourist expenditures, with nearly 7.5 million visitors and $11.9 billion in expenditures. Total visitor days also increased 7.7% to 68.2 million days (Hawaii DEBDT, 2005).

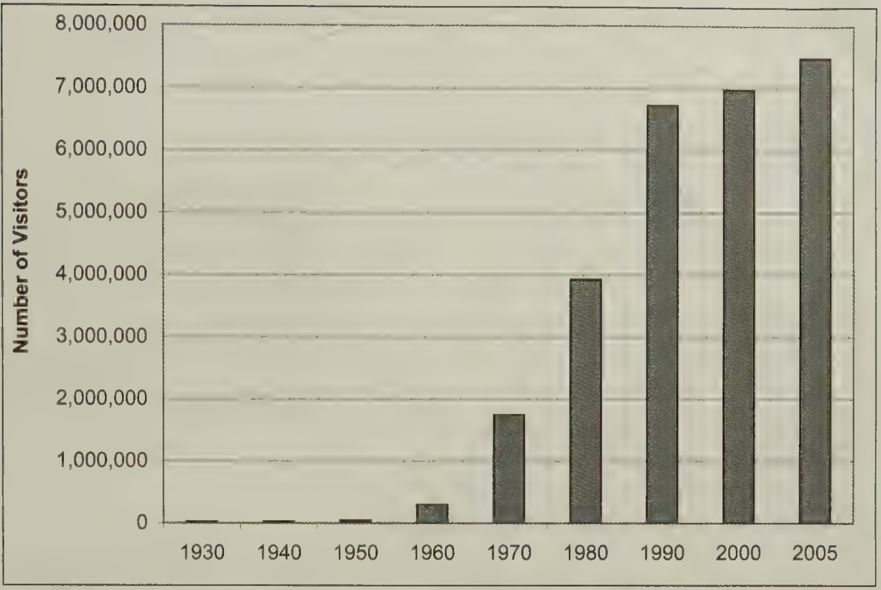


*Figure 8.15. Number of visitors to Hawaii, 1930-2005. Source: Hawaii DBEDT.*

Visitation to Hawaii is growing as the sector expands, with the three Hawaii-based inter-island cruise ships that carry over 2,000 passengers a trip, and the 2007 launch of an inter-island ferry. It is believed that the ferry service will increase outer island visitation levels not only by international and domestic tourists but also by the resident population. The island of Maui continues to attract the bulk of its visitors from the domestic market and accounted for 25.3% of the state total visitor days in 2005. The Big Island had the largest increase in the number of visitors at 18.8%, with growth from both the domestic and international markets. With the elimination of pineapple agriculture and the development of two world-class resorts, the island of Lanai has seen a huge increase in tourism although the total numbers are still small compared to the larger, more developed islands (Figure 8.16).

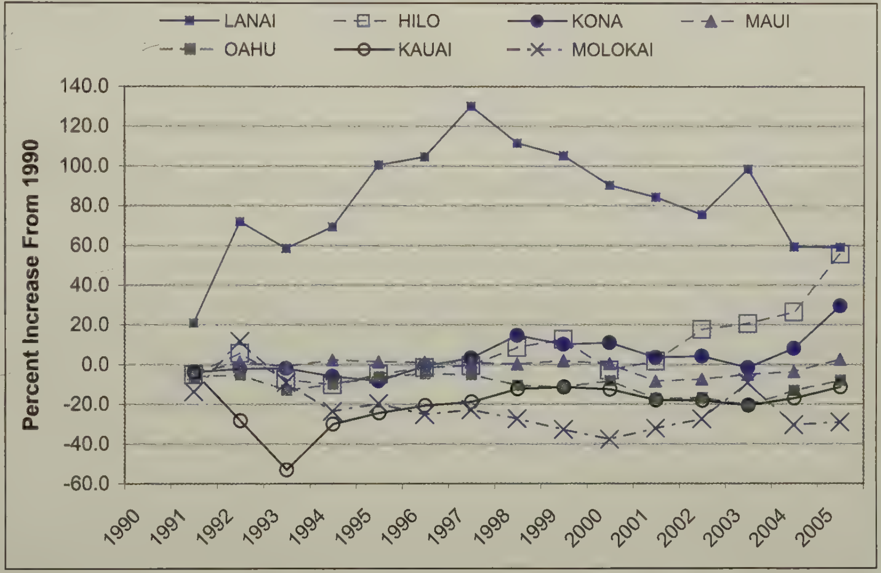


*Figure 8.16. Percent increase in tourist arrivals from 1990 at major airports on Hawaii. Source: Hawaii DBEDT.*

Recent market research and polling results have shown that increased tourism is having a negative effect on local residents as visitors increasingly seek out remote locations that were traditionally used by residents (MTP Inc., 2006). Sixty-two percent of all respondents in 2006 indicated that they felt the islands were being run for tourists at the expense of local people, representing a 14% increase in negative attitudes in just four years. In 2005, 44% of households surveyed indicated that preservation of natural and open space was worse than in previous years (MTP Inc., 2006). In addition, on the days when the cruise ships are in port, popular sites are experiencing heavy use during the pulse of activity that occurs while the cruise ship passengers are ashore. In communities across the state, residents are seeking mechanisms to limit further use to minimize potential user impacts.

Over 82% of Hawaii's tourists participate in some form of ocean recreation, from sunbathing and swimming, to snorkeling and surfing, to jet skiing and parasailing (Hawaii DBEDT, 2005). Most, if not all, of this activity occurs around Hawaii's coral reefs that generate almost $364 million each year in added value (Cesar and van Beukering, 2004). In 2005, nearly 42% of all visitors participated in diving or snorkeling activities during their stay in Hawaii, however participation by visitors from the East such as Japan was markedly lower at 19.5% (Hawaii DBEDT, 2005). Participation in snorkeling and scuba diving was 10% lower in 2005 than in 2002. Many of Hawaii's Marine Life Conservation Districts are important destinations for diving and snorkeling tourism (Figure 8.17). Often the most popular sites

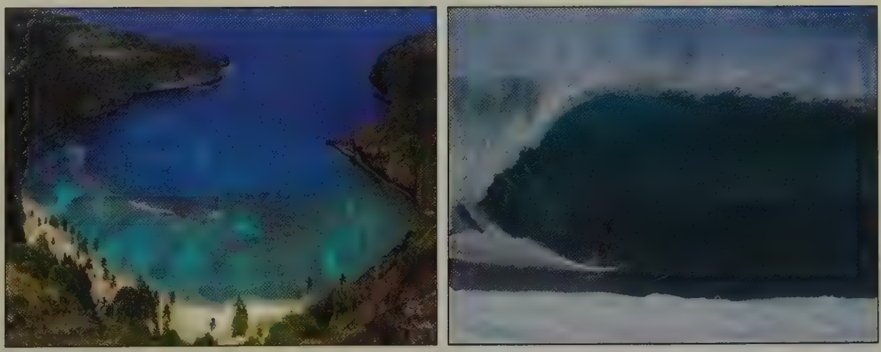


*Figure 8.17. Left: Hanauma Bay receives nearly one million visitors a year and is one of the most visited marine reserves in the world. Photo: L. Kumabe Maynard; Right: Hawaii's coral reefs provide world famous surfing spots like the Banzai Pipeline on Oahu's north shore. Photo: John Stahl.*

are lacking in or have minimal shore side facilities, which increase the potential for impacts affecting the nearshore resources. New forms of ocean recreation are constantly arising and management agencies are faced with growing challenges to define the carrying capacity of the areas and how to gauge and monitor impacts.

Most Hawaii residents also engage in some form of ocean recreation on a regular basis. Results of a state-wide stratified random survey of 1,600 households conducted in 2004 and 2005 showed that ocean swimming, recreational fishing, surfing, snorkeling and subsistence fishing were the major uses of the nearshore marine environment in Hawaii (Figure 8.17, Table 8.3; Hamnett et al., 2006). The percentage of households involved in ocean activities was 10-20% higher for ethnic Hawaiians, and these households reported significantly higher average frequencies of participation per year.

*Table 8.3. Uses of the nearshore environment by Hawaii residents. Source: Hamnett et al., 2006.*

| ACTIVITY | HOUSEHOLDS | AVERAGE PER YEAR |
|---|---|---|
| Ocean swimming | 66% | 28 |
| Recreational fishing | 31% | 10 |
| Surfing | 29% | 18 |
| Snorkeling | 32% | 6 |
| Subsistence fishing | 10% | 5 |

## Fishing

Coral reefs have always been an important component of human existence in Hawaii (Kamakau, 1839; Titcomb, 1972). Following statehood, Hawaii saw a rapid growth in tourism, an increasingly urban resident population, and the continued development of shoreline areas for tourism and recreation (Shomura, 2004). These developments resulted in changes in the character of the coastal fisheries as they became dominated by recreational anglers and a greater number of part-time commercial fishers who curtailed their fishing to take advantage of more lucrative economic activities (Friedlander, 2004).

### *Commercial Fishing*

Data from the nearshore commercial fishery show total catch by handlines declining since the early 1990s, while the catch by spearfishing has increased during this same time period (Figure 8.18). Lay gillnet catch showed a peak in the early 1980s, declined sharply afterwards and has remained relatively constant since the late 1990s. Seine nets have the highest catch rates per trip among gear type, followed by lay gill net, spear and handlines (Figure 8.18). From 1966 to 1971, the average catch per trip by seine nets, excluding coastal pelagic species, was 736 lbs, while the average declined to 480 lbs/ trip from 2001 to 2006 (Figure 8.19). During the former time period, the catch was composed of surgeonfishes (28%) followed by bonefish (24%), jacks (19%) and Pacific threadfin (11%). Since 2001, the catch composition has been dominated primarily by goatfishes (34%) and surgeonfishes (34%) and shows a shift towards lower valued species.

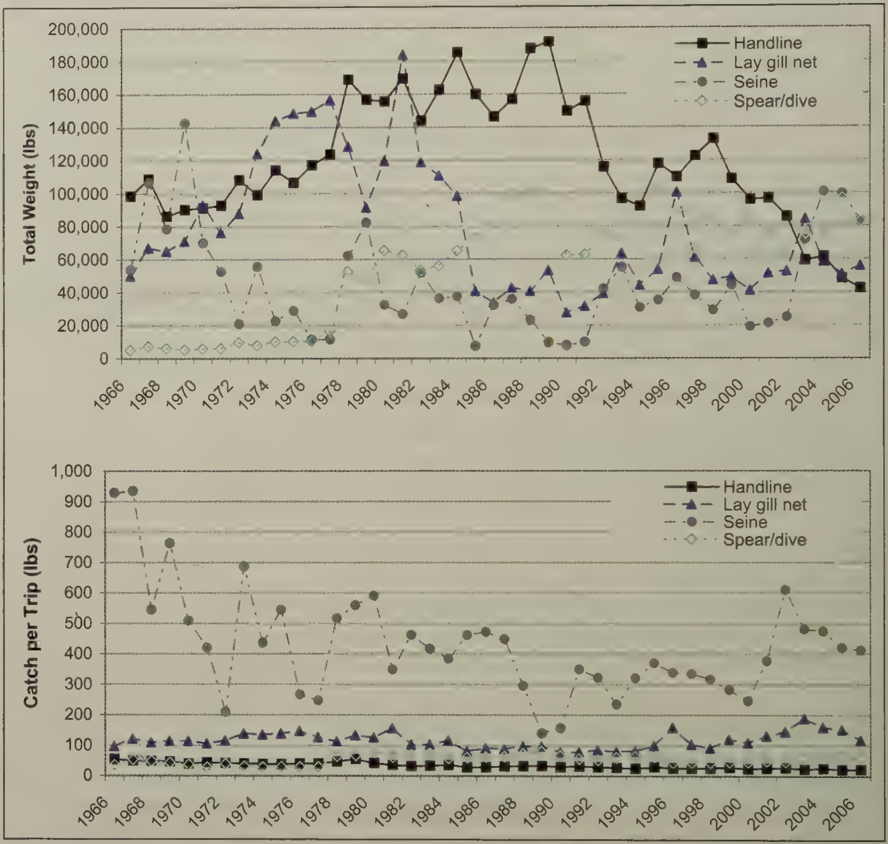


*Figure 8.18. Total catch in pounds for the major gear types (top); catch per trip in pounds of the dominant gear types (bottom). Source: Hawaii DAR commercial catch records.*

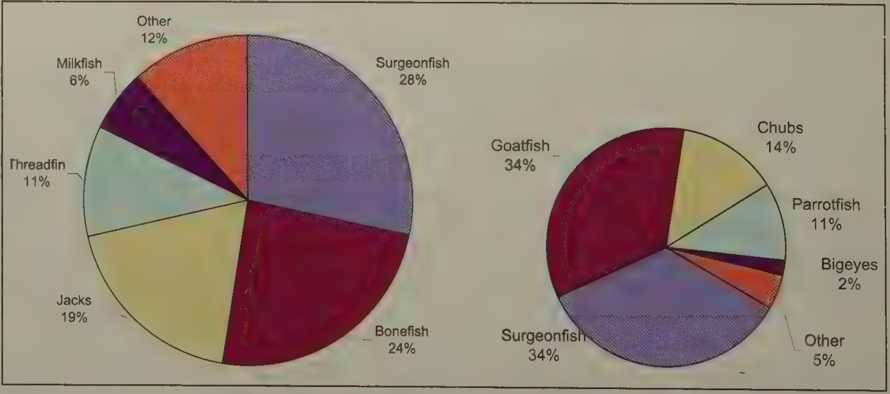


*Figure 8.19. Species composition for seines for 1966 to1971 and 2002 to 2006. Pie size is proportional to total average annual catch per unit effort for each time period. Source: Hawaii DAR commercial catch records.*

*Recreational Fishing*

The catch of coral reef species in Hawaii is dominated by recreational and subsistence fishers who are not required to report their catch (Friedlander and Parrish, 1997; Everson and Friedlander, 2004; Zeller et al., 2005). The increase in the number of registered vessels (Figure 8.20), many of which are used for fishing, and changes in the demographic and economic situation in Hawaii has likely led to an increase in the non-commercial catch of coral reef species over time.

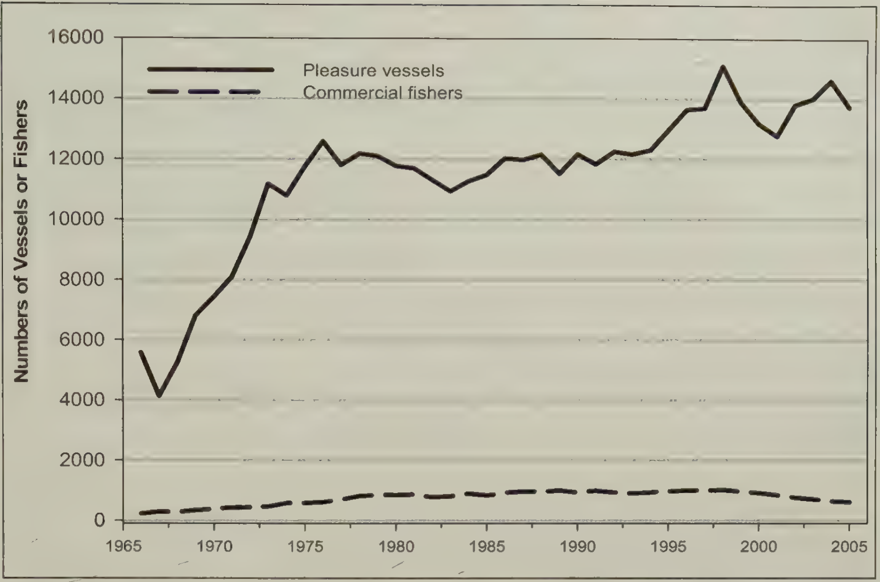


*Figure 8.20. Numbers of registered pleasure vessels in Hawaii and registered commercial fishers who recorded some coral reef catch. Source: Hawaii DBOR.*

Beginning in 2001, the National Marine Fisheries Service (NMFS) and the Hawaii Division of Aquatic Resources (DAR) began collecting marine recreational fishery data, administered through the Hawaii Marine Recreational Fishing Survey (HMRFS). Results from the 2006 survey show the recreational catch was dominated, numerically, by goatfishes, surgeonfishes and jacks (Table 8.4). Jacks are highly prized in Hawaii and the contribution by weight of these species is disproportionately high when compared to their numerical abundance. In contrast, the catch of goatfishes is dominated by seasonal runs of juveniles that tend to congregate in nearshore areas where they are easily captured but contribute less by weight than their numbers suggest. Hawaii's nearshore fisheries target hundreds of species with dozens of gear types and numerous landing locations, and the difficulties inherent in quantifying such patchily distributed recreational fishing effort over enormous areas of shoreline suggest that the results from the HMRFS should be used with caution.

*Table 8.4. Expanded catch by recreational anglers based on HMRFS data for 2006. PSE stands for proportional standard error, expresses the percent standard error of the estimate. Source: HMRFS, http://www.hawaii.gov/dlnr/dar/surveys/.*

| FAMILY | SPECIES (COMMON NAME) | TOTAL NUMBER CAUGHT | PSE | % OF TOTAL |
|---|---|---|---|---|
| Goatfishes | Yellowstripe goatfish | 726,895 | 17.8 | 24% |
| Surgeonfishes | Convict tang | 432,182 | 25.5 | 14% |
| Jacks | Bluefin trevally | 311,328 | 15.9 | 10% |
| Flagtails | Hawaiian flagtail | 156,415 | 31.9 | 5% |
| Damselfishes | Damselfishes | 129,943 | 45.8 | 4% |
| Wrasses | Razorfishes | 129,292 | 22.7 | 4% |
| Surgeonfishes | Goldring surgeonfish | 111,221 | 62.7 | 4% |
| Wrasses | Other wrasses | 91,702 | 18.5 | 3% |
| Mullets | Striped mullet | 89,105 | 79.9 | 3% |
| Snappers | Bluestripe snapper | 66,631 | 27.9 | 2% |

A survey of 1,600 households in 2004-2005 found that about 31%, or more than 130,000 households went recreational fishing while subsistence fishers took over 103,000 fishing trips during that year (Hamnett et al., 2006). Over 96% of the respondents from households that went fishing in 2004 said overfishing was a threat to the coral reef ecosystem, and those that fished more often considered it more of a threat than those who fished less. Additionally, all fishing households ranked overfishing a higher threat than households who did not fish (Table 8.5).

*Table 8.5. Opinion of fishing households about overfishing in Hawaii. Heavy fishing was defined as more than ≥32 recreational or ≥59 subsistence trips per year. Source: Hamnett et al., 2006.*

| | THINKS OVERFISHING IS A THREAT | THINKS OVERFISHING IS A SERIOUS THREAT |
|---|---|---|
| Light fishing households | 96% | 66% |
| Heavy fishing households | 97% | 74% |

## Trade In Corals and Live Reef Species

The commercial aquarium fishery in Hawaii has developed into one of the state's major inshore fisheries, with reported landings of over 990,000 specimens and a reported value to collectors of $1.93 million in 2006 (DAR commercial catch reports, unpub. data). As the aquarium industry is composed of both collectors and wholesalers, the overall economic value of the aquarium fishery to the state is estimated to be around 3-6 times higher than the value of the reported catch (Walsh et al., 2004).

Having been relatively stable between about 1990 and 2000, the catch and value of the fishery have nearly doubled in the past five years due in part to both an increased number of collectors and to several years of high recruitment, and therefore availability, of juveniles of the primary target organism, yellow tang (*Zebrasoma flavescens*). The importance of the Big Island to the fishery has increased since 1990, but that process has accelerated in recent years. The Big Island contributed 75.6% of the reported value of the fishery in fiscal year 2006; the Oahu catch was 22.4%, all other islands combined made up only 2.0% (Figure 8.21).

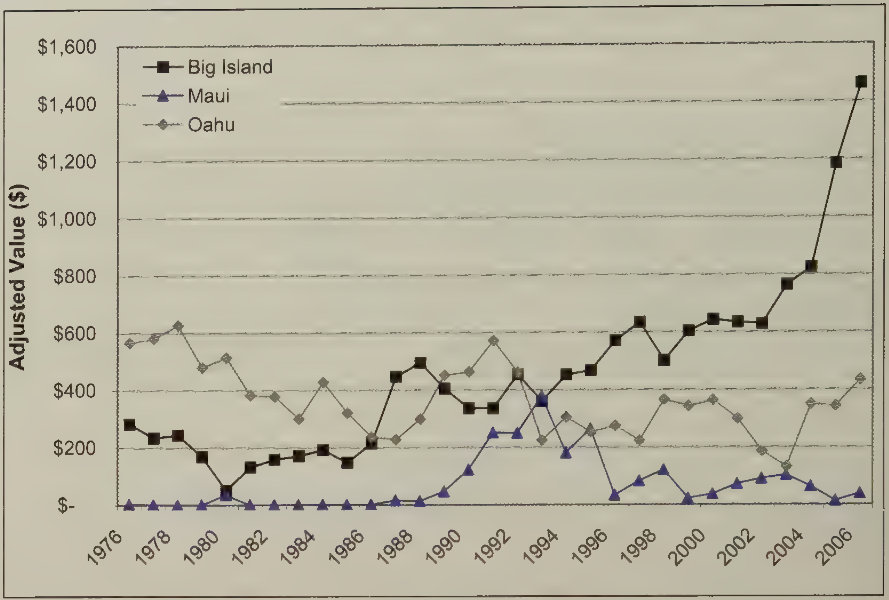


*Figure 8.21. Adjusted value (2005) of reported catch of aquarium trade organisms (fish, invertebrates, algae) by island. Data shown only for Hawaii Island, Maui and Oahu. Average reported catch from all other islands combined is $2,400 per year. Source: DAR commercial catch reports, unpub. data*

The overall aquarium catch in fiscal years 2004 through 2006 comprised 203 taxa of fish and 54 taxa of invertebrates, but a relatively small number of species dominated the catch. The top 10 taxa constituted 85.4% of the catch and 86.2% of the value over the last three years, and the yellow tang alone, made up 43.5% of catch and 57.1% of the value (Table 8.6). The catch of hermit crabs has increased dramatically in recent years and they are now the major part of the catch, but because of their low value ($0.11/crab in 2006), feather duster worms are still the most important invertebrate group by value.

*Table 8.6. Top 10 collected animals by dollar value. Dollar/year and number caught/year are averages for fiscal years 2004 to 2006. These 10 taxa constituted 85% of total catch by number, 86% by value. Source: DAR commercial catch data.*

| TAXA | COMMON NAME | ADJ $/YR | % of TOTAL | # CAUGHT/ YEAR | DOLLAR VALUE/INDIVIDUAL |
|---|---|---|---|---|---|
| *Zebrasoma flavescens* | Yellow tang | 896,048 | 57.1 | 366,317 | 2.45 |
| *Ctenochaetus strigosus* | Goldring surgeonfish | 93,202 | 5.9 | 44,202 | 2.11 |
| *Ctenochaetus hawaiiensis* | Black surgeonfish | 91,016 | 5.8 | 5,867 | 15.51 |
| *Acanthurus achilles* | Achilles tang | 69,663 | 4.4 | 12,399 | 5.62 |
| *Naso lituratus* | Orangespine unicornfish | 52,997 | 3.4 | 13,149 | 4.03 |
| *Sabellastarte sanctijosephi* | Featherduster worm | 45,485 | 2.9 | 43,143 | 1.05 |
| *Centropyge potteri* | Potter's angelfish | 38,627 | 2.5 | 7,380 | 5.23 |
| *Chaetodon tinkeri* | Tinkers butterflyfish | 29,560 | 1.9 | 379 | 78.06 |
| *Hermit crabs* | Hermit crabs | 23,759 | 1.5 | 221,178 | 0.11 |
| *Forcipiger flavissimus* | Forcepsfish | 11,682 | 0.7 | 4,966 | 2.35 |

Collection of live rock (e.g., marine substrate where living material is visibly attached), live coral, anchialine shrimp, and marine shells is poorly documented and difficult to quantify. Collection and trade of live coral and live marine rock are illegal, however, some trade still occurs, as evidenced by a number of active enforcement cases.

There are several commercial and research operations working on or actively culturing marine ornamentals, including a variety of native and alien fish and invertebrate species, artificial live rock (molded concrete, seasoned near the mouth of brackish water fish ponds so that corals and other organisms settle on them), sea horses and tridacnid clams. As yet, such trade has had no discernible effect on wild fisheries. At least one commercial operation is growing post settlement fishes for later sale. This same company is also trading in two introduced species of marine algae which are currently invasive and problematic in Hawaii.

Hawaii has had an active fishery for black coral since 1958 when this resource was discovered in abundance off Lahaina, Maui (Grigg, 1965). The majority (90%) of the harvesting targets *Antipathes cf. dichotoma*; although two other species, *A. grandis* (9%) and *Myriopathes ulex* (1%), are also harvested commercially (Oishi, 1990; Figure 8.22). This fishery is currently valued at $30 million at the retail level (Grigg, 2004). Sales have slowed since September 11, 2001 due to changes in the global economy (C. Marsh, pers. comm.).

Grigg (2004) noted changes in the fishery including: 1) an increase in demand for black corals; 2) a gradual reduction in black coral biomass over time; 3) an invasion of a non-native soft coral (*Carijoa riisei*) in certain areas of the black coral habitat; and 4) decreased recruitment. Studies conducted by DAR in the Auau Channel population suggest four changes in the population: 1) a continuing decline in the proportion of larger, older colonies above age 19; 2) fewer corals in age classes less than nine years in 2004; 3) increasing mortality rate of 30.9% for post-harvest age classes from 1975 to 2004; and 4) a decrease in recruitment during the period between about 1998 and 2004 (Figure 8.23). The most likely cause of diminished recruitment is a combination of harvest and *Carijoa* impacts, but natural fluctuations in recruitment may be a factor. To address this issue, both DAR and Western Pacific Regional Fishery Management Council are revising regulations to increase the minimum size, create a total allowable catch and create black coral protected areas.

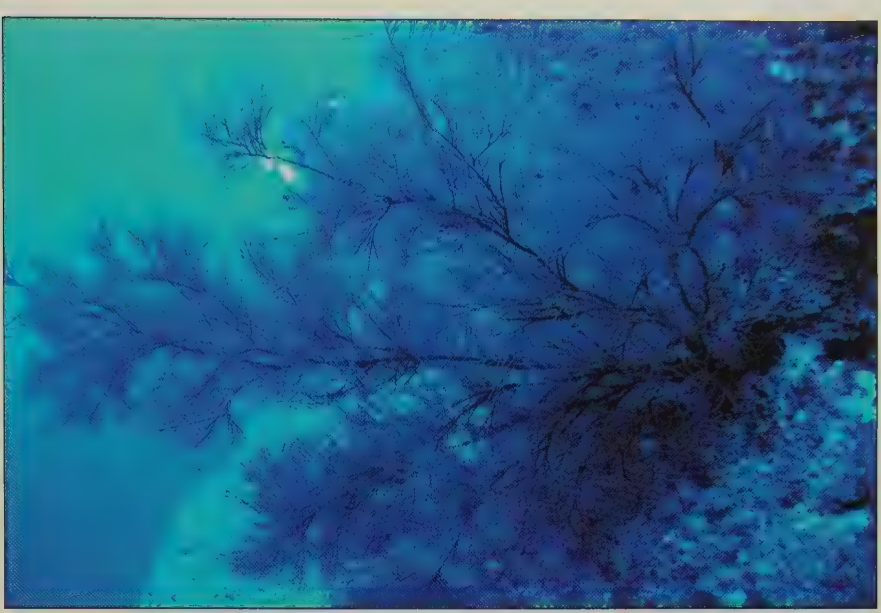


*Figure 8.22. Black coral (*Antipathes grandis*) in the Auau Channel Maui at 65 m. Source: Hawaii Undersea Research Laboratory.*

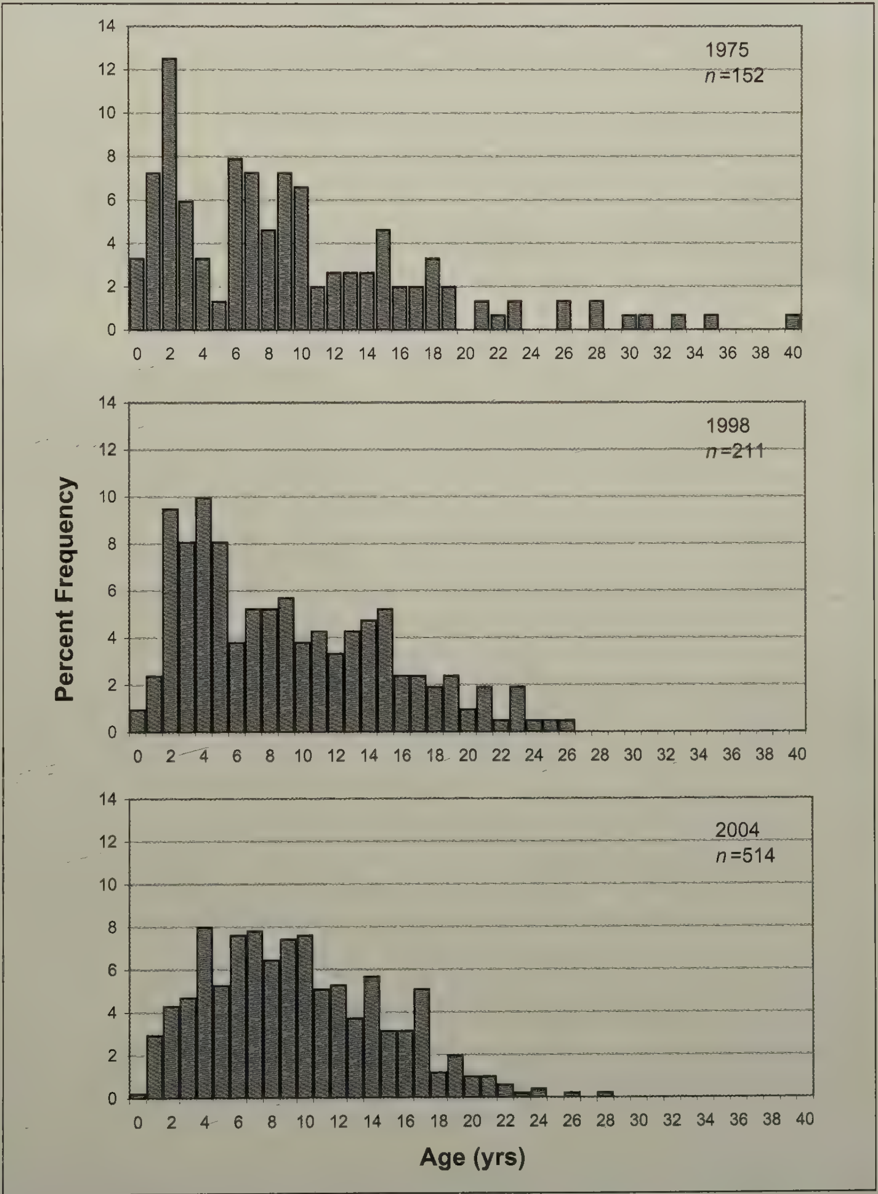


*Figure 8.23. Age frequency distributions of black coral from 1975 to 2004. Sources: Grigg, 1975 and 2001; DAR, 2004.*

## Ships, Boats and Groundings

More than 16,000 recreational and commercial vessels are currently registered in Hawaii. On average, three to five ship groundings are reported each year in the MHI, but these values are likely an underestimate as many recreational vessel groundings go unreported. In most cases, responsible parties have not had to cover the cost for vessel salvage, and restitution for damage is rarely made. Cruise ships currently make over 400 port calls annually in Hawaii, and this figure is expected to triple in the next few years. The limited port facilities have raised concerns about anchoring areas and potential reef damage.

A partial list of documented groundings that occurred around the MHI since 2005 was provided by Hawaii DAR (Table 8.7). A notable grounding occurred on February 2, 2005, when the 555 ft *Cape Flattery* ran aground on a submerged coral reef off the west coast of Oahu carrying over 30,000 tons of cement. Over 6 ha (15 acres) of coral habitat were severely damaged by the grounded ship and salvage efforts (http://www.nmfs.noaa.gov/habitat/ead/capeflattery.htm). Restoration involved securing over 800 corals to 105 cement bases to restore 3-D structure as habitat for fish and invertebrates, and provide opportunity for colony and area recovery in the future. Restored aggregate sites have been mapped, measured and marked for future monitoring of aggregate stability, survival and coral growth.

*Table 8.7. Partial list of documented vessel grounding in Hawaii since 2005. Source: Hawaii DAR.*

| BOAT NAME | LOCATION | GROUNDING DATE | BOAT TYPE | INCIDENT TYPE | DAMAGE(S) | STATUS |
|---|---|---|---|---|---|---|
| *Dolfijn* | Lahaina, Maui | 10/31/04 | private vessel | coral reef grounding | reef structural damage | removal, pending |
| *Cape Flattery* | Barbers Point, Oahu | 2/2/05 | 555 ft bulk cargo vessel | cargo vessel grounding | reef structural damage | NRDA case pending |
| *Two Star* | Honolulu, Oahu | 10/15/05 | commercial longliner | coral reef grounding | reef structural damage | 54' vessel removed |
| *Misty Blue* | Honolulu, Oahu | 10/18/05 | private recreational | coral reef/shoreline grounding | reef structural damage | 32' vessel removed |
| *Seven Stars* | Papaikou, Hawaii | 11/11/05 | commercial longliner | shoreline grounding | undetermined | 69' vessel not removed |
| *Kai Anela* | Molokini MLCD, Maui | | commercial scuba charter | sinking | reef structural damage | DLNR case pending |
| *Shangrila* | Ahihi-Kinau NAR, Maui | | commercial snorkel charter | anchor damage | reef structural damage | DLNR fined $7,304 |
| *Kaukani* | Maui | | unknown | illegal mooring | | DLNR case pending |
| *Sky Sun* | Kapoho, Hawaii | 12/15/05 | commercial longliner | shoreline grounding | undetermined. | 67' vessel removed |
| *Aukaka* | Kohala, Hawaii | 3/27/06 | commercial fishing | coral reef grounding | undetermined. | 41' vessel removed |
| *Wahine Kapaloa* | Niihau | 12/30/06 | commercial fishing | shoreline grounding | undetermined. | 44' vessel removed |

## Marine Debris

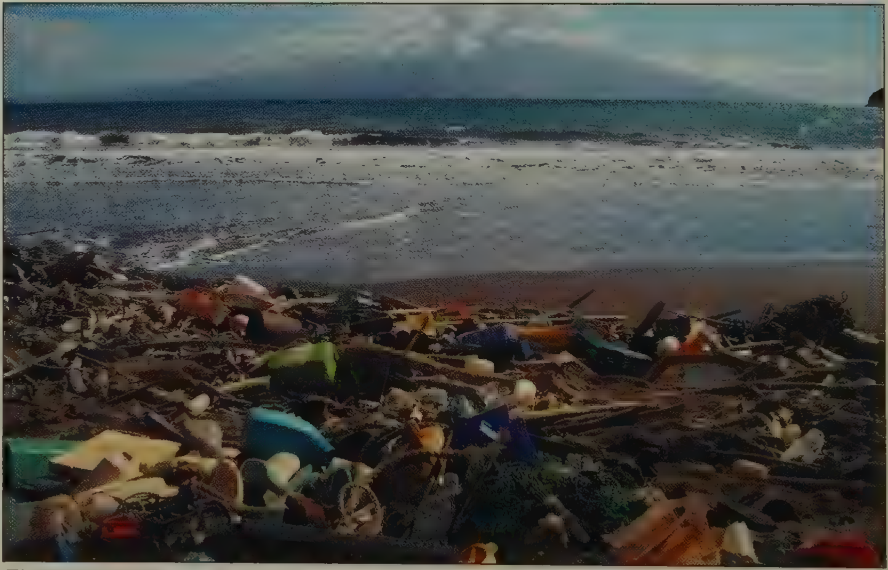


*Figure 8.24. Marine debris laden shores of Kanapou Beach, Kahoolawe. Photo: NOAA Marine Debris Program.*

Marine debris from marine and terrestrial sources continues to wash up on Hawaii's shores daily (Figure 8.24). Several formal programs and numerous community groups have initiated efforts to remove marine debris from shorelines and nearshore reef areas (Table 8.8). Marine debris, specifically derelict fishing gear (DFG), continues to present a potentially lethal entanglement hazard to various marine species of concern, including the critically endangered Hawaiian monk seal, the threatened green sea turtle and the endangered humpback whale. DFG may also cause damage to sensitive reef habitat, serve as vectors for non-native species introductions and present a hazard to navigation. In 2005, NOAA's Pacific Islands Fisheries Science Center, sponsored by the NOAA Marine Debris Program, began a project to survey for and conduct removal efforts of DFG on the shores of the MHI. Following its removal from coastal habitat, DFG is processed and incinerated to create electricity as part of Oahu's "Trash to Energy" program. Launched in January of 2006, the Honolulu Derelict Net Recycling Program (a dedicated port reception bin for derelict net at Pier 38, Honolulu Harbor) has resulted in over 15 tons of derelict net and used monofilament longline recycled to create electricity through Hawaii's supportive marine debris partners. The electricity produced enough power to supply the following:

- Main Hawaiian Islands project—about 16 homes for a year (117,182 kWh)
- Waiohinu-Ka Lae coast—about 17 homes for a year (127,590 kWh)
- Port Reception—about seven homes for one year (47,986 kWh)

Table 8.8. Marine debris removal programs in Hawaii. DFG = derelict fishing gear. Source: NOAA PIFSC.

| PROGRAM | YEAR | LOCATION | DEBRIS INFORMATION |
|---|---|---|---|
| MHI aerial survey and debris removal NOAA PIFSC (funded by NOAA Marine Debris Program) | 2006 | Big Island, Kauai, Lanai, Molokai, Maui and Oahu | 700 individual debris sites, the majority on windward shores |
| | May 2006 | Oahu | 225 DFG conglomerates, nearly 19 tons (37,317 lbs) |
| | February 2007 | Lanai | 156 conglomerates, totaling 19 tons (38,360 lbs), northern and eastern shores |
| Waiohinu-Ka Lae coast cleanup Hawaii Wildlife Fund (funded by NOAA Marine Debris Program) | 2005 | Waiohinu-Ka Lae coast, Big Island | 41 tons of debris from 14 km of coastline, 88%=DFG |
| "Get the Drift and Bag It!", Ocean Conservancy's annual International Coastal Cleanup | 2005 | Statewide (>2,000 volunteers) | 16.5 tons along 140 km of shoreline in one-day effort. 150 divers removed >670 kg from 5 km of underwater habitat |
| Kahoolawe Island Reserve Commission | 2006 | Kanapou Beach, Kahoolawe | 4.5 tons from the shoreline |
| Honolulu Derelict Net Recycling Program and Port Reception Bin (funded by NOAA Marine Debris Program) | 2005 | Pier 38, Honolulu Harbor | 15.5 tons of derelict net and monofilament line recycled to create electricity |

In the 2005 "Get the Drift and Bag It!" event, a part of the Ocean Conservancy's annual International Coastal Cleanup, over 2,000 volunteers across the state collected nearly 16.5 tons of marine debris along 140 km of shoreline in this one-day effort. Of all the debris types noted, cigarettes, caps and lids and food wrappers were the most common, accounting for 55% of the debris removed (the Ocean Conservancy, 2006).

Additionally, many small-scale beach cleanups take place on every island at least a few times a month, and are hosted by various non-profits, communities and school groups. In addition to continued removal of marine debris, outreach and education efforts, along with partnership building, need to be increased to address this issue locally, as well as nationally and internationally with Pacific Rim communities that share the impacts and responsibility for marine pollution.

### Aquatic Invasive Species

The Hawaii Marine Algae Group (HIMAG) has worked since 2002 to develop methods to manage non-indigenous species and invasive algae and develop capacity among interested community groups to better manage nearby coastal regions. This group includes DAR, University of Hawaii Departments of Botany and Biology and The Nature Conservancy. The target group of invasive species includes eight algae, six of which have a known history of introduction to the state of Hawaii, and are detailed in Table 8.9.

The community-based alien algae cleanup events that began in Waikiki in 2002 (Figure 8.24) have since spread to other locations where motivated communities have partnered with the above agencies to stage their own alien algae remediation efforts. Community groups and teachers such as Paepae O Heeia, stewards of Heeia Fish Pond (Kaneohe, Oahu),

Table 8.9. Summary information for invasive and non-indigenous algae in Hawaii 2006. Source: HIMAG.

| KNOWN INVASIVE ALGAE | ORIGIN/MECHANISM OF INTRODUCTION | IMPACT REGIONS IN MHI | METHODS FOR MANAGEMENT |
|---|---|---|---|
| *Acanthophora spicifera* (Rhodophyta) | Guam/Hull fouling on vessel in Pearl Harbor Naval Station | MHI, especially intertidal regions | Under development by USFWS-funded research |
| *Avrainvillea amadelpha* (Chlorophyta) | Unknown. Genus has cosmopolitan distribution in warm waters | Malama Bay from Hanauma Bay to Kahe Pt, Oahu | Under development by HCRI-funded research |
| *Dictyota flabellata* (phaeophyte) | San Diego, CA/Hull fouling on vessel in Barber's Pt., Oahu | Potential risk to reef community Kalaeloa, Oahu | None |
| *Eucheuma denticulatum* (Rhodophyta) | Philippines/Permitted introduction | Kaneohe Bay to Kaaawa, O'ahu | Super sucker |
| *Gracilaria salicornia* (Rhodophyta) | Hilo Bay/Inter-island introductions to Oahu, Molokai | Waikiki and Kaneohe Bay, Oahu. Eastern leeward reef Molokai | Super sucker |
| *Gracilaria tikvahiae* (Rhodophyta) | Florida/Permitted introduction | Marsh regions on Oahu | Under study with HCRI-funded research |
| *Hypnea musciformis* (Rhodophyta) | Florida/Non-permitted introduction | Kihei and Kahului Maui | Daily/periodic bulldozer use for beach cleanups |
| *Kappaphycus alvarezii* (Rhodophyta) | Philippines/Permitted introduction | Kaneohe Bay, Oahu | Periodic manual removal |

and Michelle Kapana Baird of Kaiser High School (Maunalua Bay, Oahu) are currently restoring native nursery and reef habitats in their local areas. Their efforts are contributing significantly to the scientific understanding of these invasive species by working closely with University of Hawaii researchers. These efforts are also helping to improve best management practices in controlling the threat of invasive marine algae throughout the state.

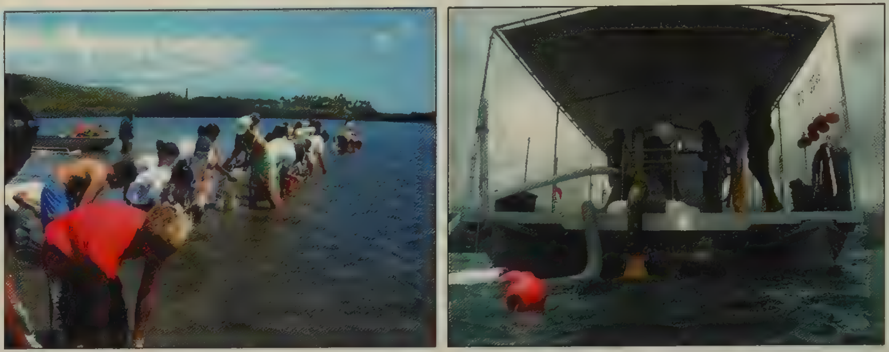


Figure 8.25. Community algae cleanup in Kaneohe Bay (left) and Supersucker used to vacuum invasive algae in Kaneohe Bay, Oahu (right). Photos: E. Co.

In addition, the HIMAG group continues to refine the remediation process involving the "Super Sucker", an underwater vacuum set upon a floating platform, capable of efficiently removing large amounts of alien marine algae in remote locations using a small group of highly trained technicians and scientists (Figure 8.25). This operation continues to restore native reef habitat in Kaneohe Bay. Guided and supported by the HIMAG group, early success of the Super Sucker has also resulted in the fabrication of a second operation led by the DAR, endearingly dubbed "Super Sucker Jr." to compliment the efforts of the original unit in other high-priority locations. Lastly, very small units have also been developed by the HIMAG group, known as "Mini Suckers", designed to operate with community groups in shallow areas along the coastline. These small units have done well to bridge the gap among the range of restoration approaches from efficient alien algae control techniques to critical education and outreach of these serious threats to Hawaii's nearshore marine environment.

DAR has conducted extensive surveys to document the distribution of key alien algae species and prioritize specific areas for control efforts (Figure 8.26). These survey areas include the Hilo coast, south Molokai, South Oahu (Barbers Point to Hanauma Bay) and Windward Oahu (Kahuku to Waimanalo).

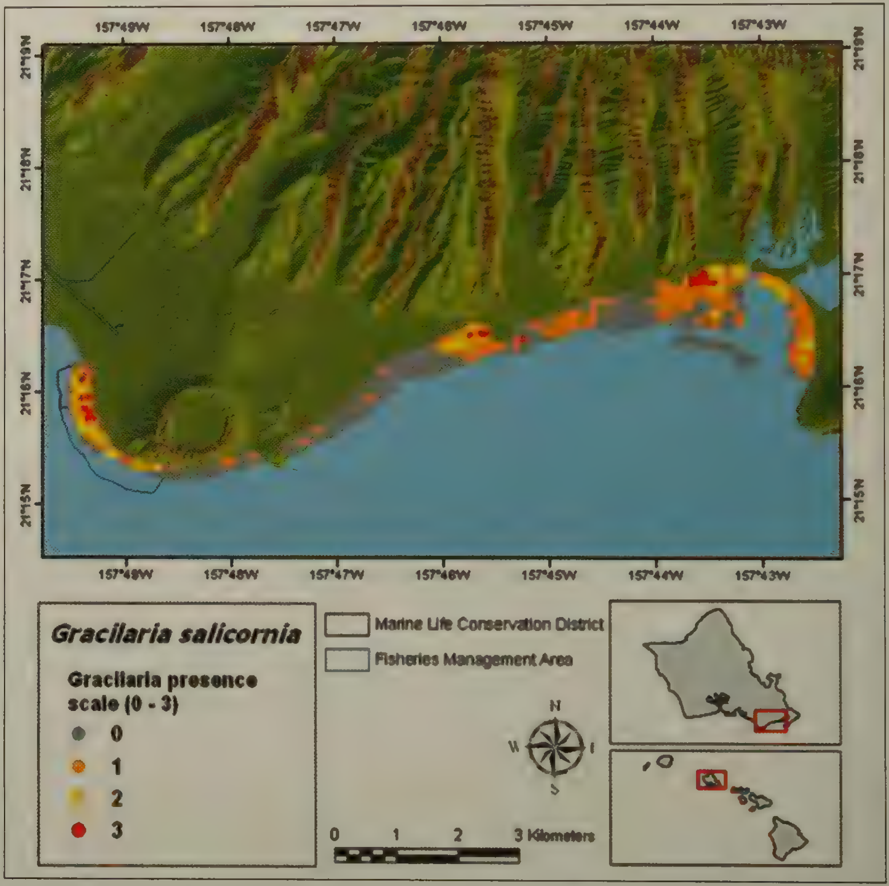


Figure 8.26. A map of Maunalua Bay shows the distribution of the invasive algae Gracilaria salicornia. Data: Hawaii, DAR.

A compendium of all alien species in Hawaii is being developed by Eldredge and Carlton and will include all invertebrates, algae and fishes. A recent introduction of concern is the Orange Keyhole Sponge (*Mycale armata thiele*) which was unknown in Hawaii prior to 1996 (Figure 8.27). A two-year study suggests that growth and spread of *M. armata* in Kaneohe Bay, Oahu may be slowly extending beyond its area of highest concentration in the southern portion of the bay (Coles et al., 2007).

In addition, DAR began an effort in 2004 to eradicate the snowflake coral, *Carijoa riisei*, from areas of Kauai. This attempt has mostly concentrated on wrapping pier pilings in Port Allen Commercial Harbor to eliminate the presence of *C. riisei* from the harbor. *Carijoa's* distribution is limited to pier pilings in the harbor; however, there are four confirmed locations with small populations of *Carijoa* outside Port Allen on Kauai. Surveys suggest that *Carijoa* is not currently widespread and may be at a level that can be eradicated if methods can be developed.

Nearly 16,000 fish of 12 species, particularly snappers and groupers, were intentionally introduced to Hawaii in the late 1950s and early 1960s, but only three, the blue-lined snapper (*Lutjanus kasmira*), the peacock grouper (*Cephalopholis argus*) and the black-tailed snapper (*Lutjanus fulvus*), have become established to any large extent. The first two species have proven to be particularly controversial as they have adapted well to Hawaiian waters and are often blamed for depletion of desirable species due to competition or predation.

Blue-lined snappers were only introduced to Oahu but have subsequently spread to form patchy distributions throughout the entire archipelago (Randall, 1987; Sladek-Nowlis and Friedlander, 2004). In Hanalei Bay, Kauai, densities of blue-lined snapper are high but have decreased in the past few years from a peak in 1999 (Figure 8.28. Friedlander et al., 2002; Friedlander and Brown, 2006). Density of blue-lined snapper is two orders of magnitude lower in Kona, Big Island, but has shown an increase in number in the past few years (Figure 8.28).

Studies of blue-lined snapper diets have not detected appreciable predation on native species in shallow-water habitats (Oda and Parrish, 1982; DeFelice and Parrish, 2003). However, at high densities, blue-lined snapper appear to alter the schooling behavior of the native yellowfin goatfish (*Mulloidichthys vanicolensis*) by displacing them higher into the water column (Schumaker and Parrish, 2005). Although blue-lined snappers consume some fish in their diets, most of their diet is composed of small, cryptic species of no commercial or recreational value (Schumaker, unpub. data).

Approximately 2,385 peacock grouper were introduced to the MHI in the late 1950s and now occur on all of the MHI and in low numbers in the NWHI. Although it was introduced to augment declining populations of food and game fishes, it has not been well received by most fishermen due to concerns about ciguatera poisoning. Peacock grouper have been blamed for a multitude of problems on the reefs, most notably a decline in important aquarium fish and putative impacts on food fishes and invertebrates.

On the Kona coast, peacock grouper populations increased between 1999 and 2006. However, in 2006, there was a marked downturn in abundance. This recent decline may be related in part to an unusual fish die off in West Hawaii which first became apparent in May 2006. Peacock grouper were by far the most common species to die, but a number of other species, comprising a wide range of families, feeding types and depth ranges, also perished. Similar undocumented reports of floating fish (typically peacock grouper) were received from Maui, Oahu and Molokai. Necropsy from the National Wildlife Health Center, USGS in Honolulu reported swim bladder distension, a variety of incidental lesions and, in two cases, atrophy of the liver. No gross or microscopic lesions were considered severe enough to cause death and the cause of death remains unknown.

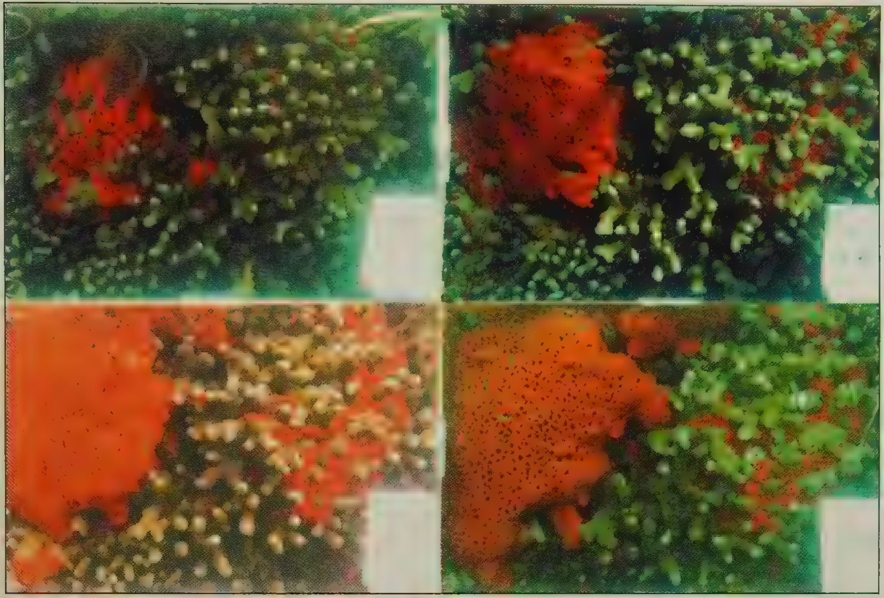


*Figure 8.27.* Mycale armata *overgrowth in Kaneohe Bay from 2004 to 2006. Source: Coles et al., 2007.*

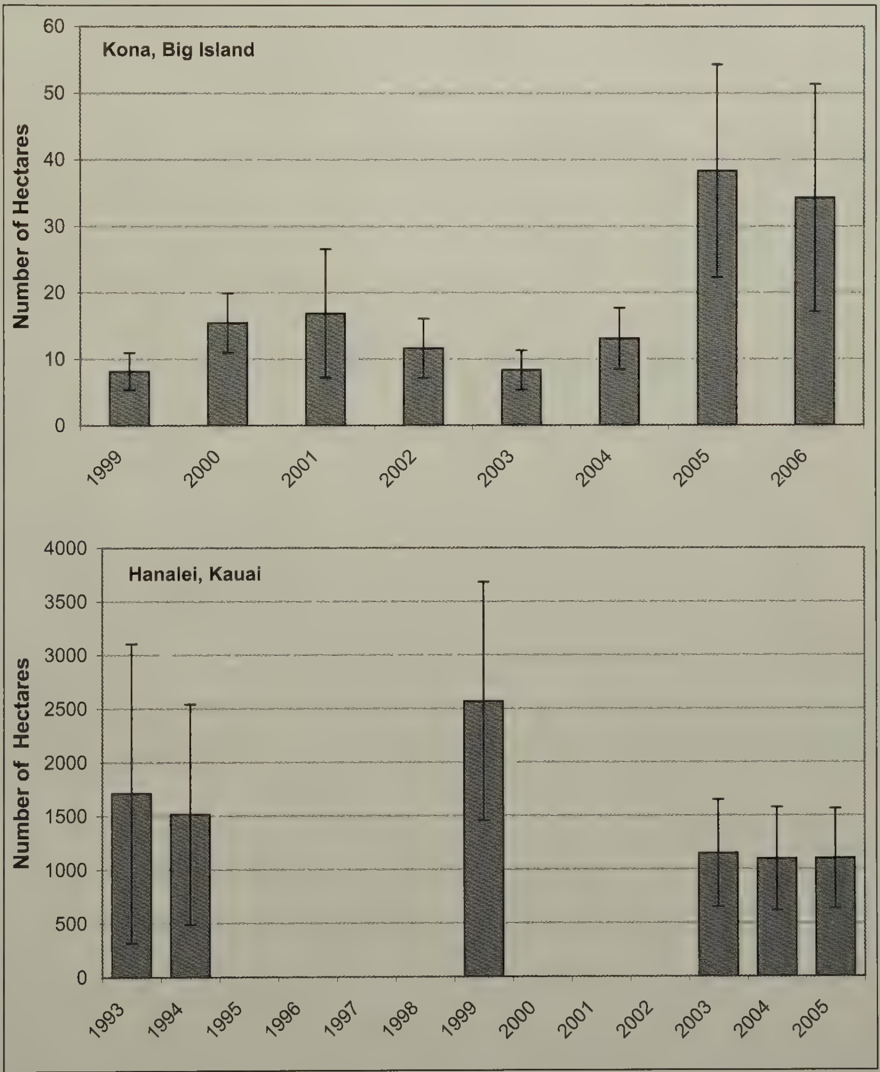


*Figure 8.28. Density of blue-lined snapper (*Lutjanus kasmira*) in Hanalei, Kauai and Kona, Big Island. Values are means and standard error. Note differences in y-axis scale. Source: Hawaii DAR; Friedlander; unpub. data.*

## Security Training Activities

Members of the public have limited or no access to the shoreline and nearshore waters within and around military or security areas on Oahu (Pearl Harbor, Kaneohe Bay Marine Corps Base Hawaii and Honolulu Reef Runway) and Kauai (Barking Sands Pacific Missile Range Facility).

## Offshore Oil and Gas Exploration

No offshore oil and gas exploration occurs in Hawaiian waters.

## Other

### *Crown-of-thorns Sea Stars (Acanthaster planci)*

Crown-of-thorns sea stars (COTS) are corallivores that have caused significant coral damage throughout the Indo-Pacific. Their abundance is monitored on the reefs of Hawaii during benthic and towed-diver surveys. Towed-diver surveys indicate that COTS occur on reefs throughout Hawaii at low levels (average=3.4 COTS/hectare; PIFSC-CRED, unpub. data). However, there have been several reports of localized outbreaks of COTS around the islands. During a recent outbreak in July 2005 (Figure 8.29), hundreds of COTS were found within a one km$^2$ area of reef off the north shore of Oahu (Kenyon and Aeby, in review). In August 2006, towed-diver surveys also identified several smaller, localized outbreaks on Mana Reef off the leeward coast of Kauai (PIFSC-CRED unpub. data).

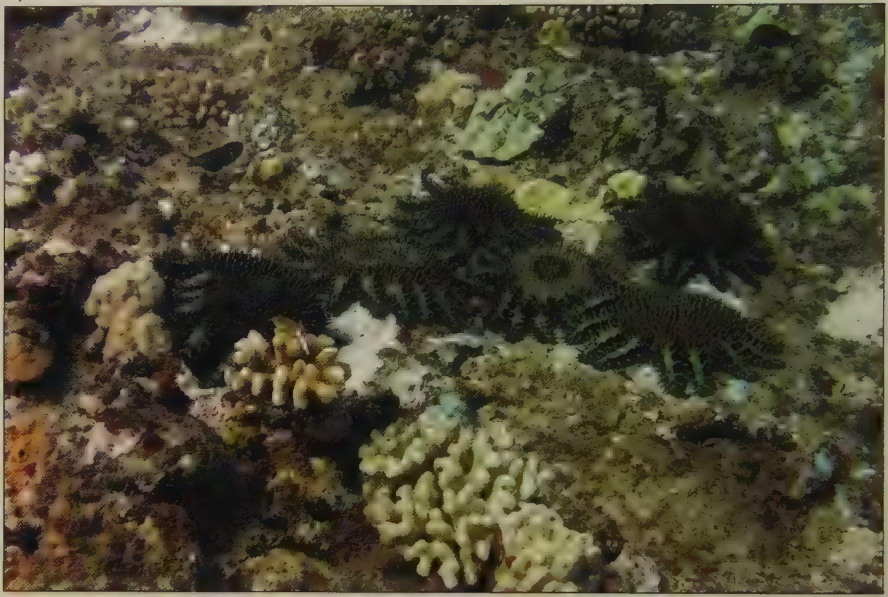


*Figure 8.29. Localized outbreak of COTS off Oahu. Photo: J. Kenyon.*

## CORAL REEF ECOSYSTEMS—DATA-GATHERING ACTIVITIES AND RESOURCE CONDITION

Current coral reef monitoring, research and assessment activities, including those that are represented in this report, are summarized in Table 8.10. Monitoring locations are shown in Figure 8.30.

*Table 8.10. Monitoring programs investigating coral reef ecosystems in the MHI.*

| PROGRAM AND OBJECTIVES | START DATE | FUNDING | PARTNERS |
|---|---|---|---|
| DAR marine managed area monitoring program | 1970s | USFWS | DAR |
| Kahe Point Coral monitoring of long-term trends in coral community | 1973 | HECO | HECO, AECOS, Sea Engineering |
| Hanalei Bay Marine Communities Investigation<br>Trends in benthic and fish assemblages | 1992 | NOAA, DAR, USGS, Hanalei Heritage River | NOAA, DAR, Hanalei Heritage River Hui, HIMB |
| Coral Reef Assessment and Monitoring Program (CRAMP)<br>Monitoring of benthos and fish statewide | 1997 | USGS, EPA | UH-Manoa, NOAA, DAR |
| Reefcheck<br>Volunteer community-based monitoring protocol to measure coral reef health | 1996 | NOAA, CZM, DAR | Oceanwide Sci. Instit., Waikiki Aquarium, Windward C.C., Hawaii Pacific Univ., Hanauma Bay Edu. Center, MOP |
| DAR Statewide Coral Reef Monitoring Program.<br>Integrated monitoring of fish, benthos, and coral condition on Oahu, Maui and Big Island | 1999 | NOAA, HCRI | UH-Hilo, UH-Manoa, NPS |
| Reef Watchers Program<br>Volunteers monitor and provide data on nearshore and inter-tidal sites | 1999 | CZM/DBEDT, NFWF, NOAA, Harold Castle Foundation, HCF, TNC, CCN DAR, TNC, CCN | DOE, UH-Hilo, Washington State University and West Hawaii participating residents |
| USGS Study of Coral Reefs in the Pacific<br>Mapping, monitoring, remote sensing, sediment transport studies, collection of tide, wave and current data. | 2000 | USGS | USGS, UH-Manoa, HIMB, DAR, NPS |
| The Reef Environmental Education Foundation (REEF)<br>Volunteer scuba divers and snorkelers collect information on marine fish populations | 2001 | CZM, NFWF, PADI – Project Aware, NOAA, NMSP | Maui Comm. College MOP, Project SEA-Link, Hawaii Coral Reef Network, DAR |
| Fish Habitat Utilization Program (FHUP)<br>Fish habitat utilization patterns, MPA effectiveness statewide | 2002 | NOAA DAR, | NOAA, UH-Manoa, UH-Hilo, HIMB, NPS |
| Kapoho Reef Watch<br>Monitor human use, water quality and marine biota around Waiopae tide pools | 2003 | HCF, NFWF, TNC, Harold K. L. Castle Foundation | Vacationland Hawaii Comm. Assoc, Kapoho Kai Water Assoc. Cape Kumukahi Foundation, NOAA, USFWS |
| Nuisance algae in W. Maui; linkages of physical and biological processes related to nuisance algae | 2003 | NOAA, HCRI | NOAA, DAR, UH-Manoa, USGS, HIDOH |
| MHI Rapid Assessment and Monitoring Program<br>Mapping, assessment, monitoring of benthos, fish, coral disease, oceanography. | 2005 | NOAA | UH-Manoa, UH-Hilo, HIMB, Bishop Museum, DLNR DAR |
| National Park Service<br>Long-term monitoring of benthos and fish at four parks | 2006 | NPS | NOAA, UH-Hilo |
| Alien Algae<br>Mapping for presence/absence and relative abundance | 2006 | DAR/ HISC | UH-Manoa / NOAA statewide with focus on Oahu, Molokai, and Hawaii |
| DAR Study on impact of lay gill net regulations on Maui and Oahu (2007-2011). Broad spatial scale surveys of herbivorous fish and benthic algae around sites on Oahu and Maui subsequent to ban on use of lay gillnets enacted in early 2007 | 2007 | USFWS | TNC |

AECOS – AECOS Inc. Environmental Consulting Company
CCN – Community Conservation Network
CZM – Hawaii Coastal Zone Management
DAR – Hawaii Department of Land and Natural Resources, Division of Aquatic Resources
DOE – Hawaii Department of Education
HIDOH – Hawaii Department of Health
EPA – Environmental Protection Agency
HCF – Hawaii Community Foundation
HCRI – Hawaii Coral Reef Initiative Program
HECO – Hawaii Electric Company
HIMB – Hawaii Institute of Marine Biology
MOP – Univ. of Hawaii Marine Options Program
NOAA – National Oceanic and Atmospheric Administration
NFWF - National Fish and Wildlife Foundation
NMSP – National Marine Sanctuary Program
NPS – National Park Service
PADI – Professional Association of Diving Instructors
UH – University of Hawaii
USFWS – U.S. Fish and Wildlife Service
USGS – U.S. Geological Survey
VHCA – Vacationland Hawaii Community Association

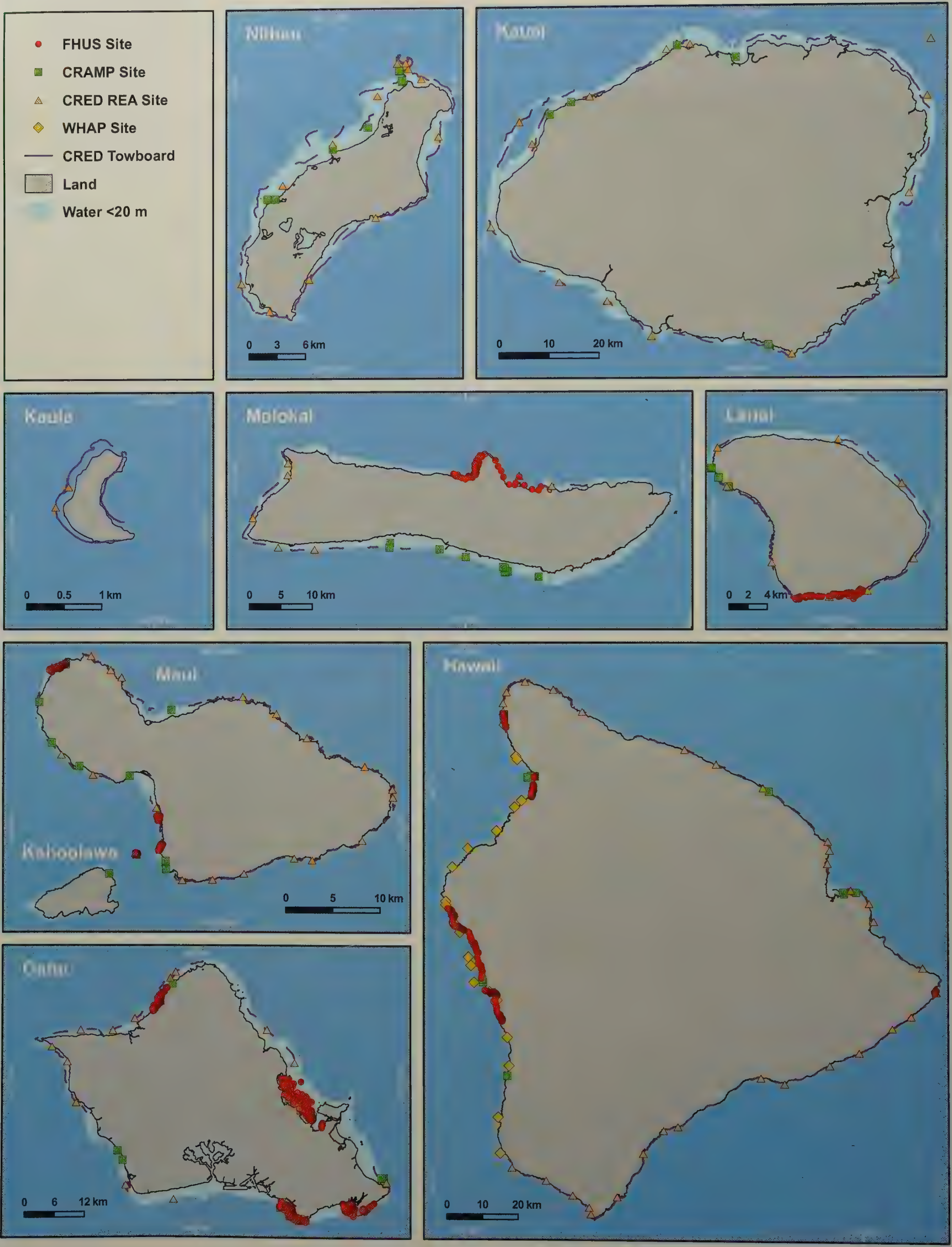

FHUS Site
CRAMP Site
CRED REA Site
WHAP Site
CRED Towboard
Land
Water <20 m
Niihau
0 3 6 km
Kauai
0 10 20 km
Kaula
0 0.5 1 km
Molokai
0 5 10 km
Lanai
0 2 4 km
Maui
Kahoolawe
0 5 10 km
Hawaii
0 10 20 km
Oahu
0 6 12 km

*Figure 8.30. Monitoring locations in the MHI. Map: K. Buja.*

## WATER QUALITY AND OCEANOGRAPHIC CONDITIONS

There are no comprehensive, state-wide water quality monitoring programs that specifically assess sediment or chemical impacts to coral reef areas in Hawaii. Water quality monitoring is undertaken for a variety of purposes across different spatial and temporal scales by federal and state resource agencies, private consultants, non-governmental organizations (NGO's) and University researchers. Examples of these monitoring activities are highlighted below.

### PIFSC-CRED Monitoring

NOAA's PIFSC-CRED has begun monitoring coral reefs and water quality throughout the MHI once every 1 to 2 years as part of the Reef Assessment and Monitoring Program (RAMP) cruises and provides a snap-shot of water quality parameters at a limited number of locations. As part of the RAMP effort, the PIFSC-CRED Oceanography Team analyzed water samples for concentrations of chlorophyll a and the nutrients nitrogen, phosphorus and silicon.

### Hawaii Department of Health Monitoring

Water quality at beaches is regularly monitored for bacteria that indicate a risk to human health. Pollutant concentrations normally decrease sharply with distance from shore, and offshore water quality in Hawaii is generally good. HIDOH regularly monitors indicator bacteria (*Enterococcus*) at swimming beaches. In recent years, HIDOH has also collected data on turbidity, nutrients and chlorophyll a at shoreline stations in knee-deep water and in perennial streams. HIDOH uses these data, and other available data that meet specific quality criteria, to identify streams and coastal segments that are "water quality impaired" (e.g., where state water quality criteria are regularly exceeded). A list of impaired waters is reported to the EPA every two years, as required by the Federal Clean Water Act. Although the listings are a function of available data rather than the result of a comprehensive, state-wide sampling design, it is not surprising that the number of listed waters corresponds, roughly, with island population size (Table 8.11).

*Table 8.11. The Hawaii 2006 Draft Section 303(d) list identifies the number of water quality impairments for both streams and coastal waters. Source: HIDOH.*

| | NUMBER OF LISTINGS | | | | |
|---|---|---|---|---|---|
| **ISLAND** | ***Enterococcus*** | **Total Nitrogen** | **Nitrate + Nitrite** | **Total Phosphorus** | **Turbidity** |
| Kauai | 18 | 12 | 13 | 1 | 39 |
| Oahu | 31 | 79 | 62 | 47 | 95 |
| Molokai | 0 | 0 | 0 | 0 | 4 |
| Lanai | 0 | 0 | 1 | 0 | 4 |
| Maui | 6 | 24 | 32 | 11 | 75 |
| Hawaii | 9 | 20 | 15 | 13 | 35 |
| **TOTALS** | **64** | **135** | **123** | **72** | **252** |

HIDOH has just released the final 2006 integrated report of assessed waters in Hawaii (HIDOH, 2008). The 2006 Integrated Report is the first effort by the HIDOH to integrate its reporting requirements for the Federal Clean Water Act. It includes Hawaii's 2004 list of impaired waters and data collected from state surface water bodies over the past six years. It reports that overall quality of Hawaii's waters is very good and the majority of the coastal waters and upland surface waters are in good condition (HIDOH, 2008). The overall quality of Hawaii's groundwater is generally considered excellent and the chemical contaminant concentrations that have been detected in public groundwater/drinking water sources are generally below state and federal drinking water standards (HIDOH, 2008).

The impaired coastal waters are primarily harbors, semi-enclosed bays and protected shorelines, where mixing is reduced and resident time of pollutants is long when compared with exposed coasts. Several bays that have coral reefs, such as Kaneohe Bay and Pearl Harbor (Oahu), Nawiliwili Bay (Kauai) and Hilo Bay (Hawaii), are included on the list. Because offshore water quality is generally good and few data sets are available to characterize water quality around reefs, deeper and offshore waters where coral reefs occur are generally not included on the list. The most widely distributed coastal pollutants are nutrients, sediments and *Enterococcus* (see Table 8.11).

HIDOH's 2006 list of impaired waters contains a total of 93 streams segments and 219 coastal areas. One stream was entirely de-listed and several modifications were made within listings. Seventeen new streams were listed. For coastal waters, 42 new water bodies were listed, two were de-listed and six previously listed water bodies were listed for new pollutants. In total, there were 534 coastal water bodies, of which 270 (51%) had available data for assessment. The breakdown for the individual islands is: Kauai, 38 (45%); Oahu, 98 (54%); Molokai, 38 (8%); Lanai, 8 (44%); Maui, 76 (61%); and Hawaii, 47 (53%; HIDOH, 2008).

As a requirement of a grant from the EPA, Hawaii must submit an annual notification of any beach postings and advisories. All beach postings for 2006 were related to sewage spill events and therefore postings were performed by the respective city or county personnel. In some cases, Hawaii Department of Health Clean Water Branch Monitoring staff assisted in the posting of signs. If a sewage spill involves a group (such as hotels, restaurants, condos, etc.) that is unfamiliar with posting of warning signs, the HIDOH will post the signs and monitor the spill in the interest of rapid response to protect the public. In 2006 a total of 15.19 mi of Oahu's beaches were posted due to Raw Sewage Advisories for a total of 464 days. No raw sewage advisories were issued for the counties of Maui, Kauai and Hawaii.

The HIDOH began issuing Brown Water Advisories in 2004 to warn the public of the dangers of storm water discharges into the nearshore waters and flooded areas. The total beach miles and total numbers of days posted because of brown water advisories in each county and statewide are presented in Figure 8.31.

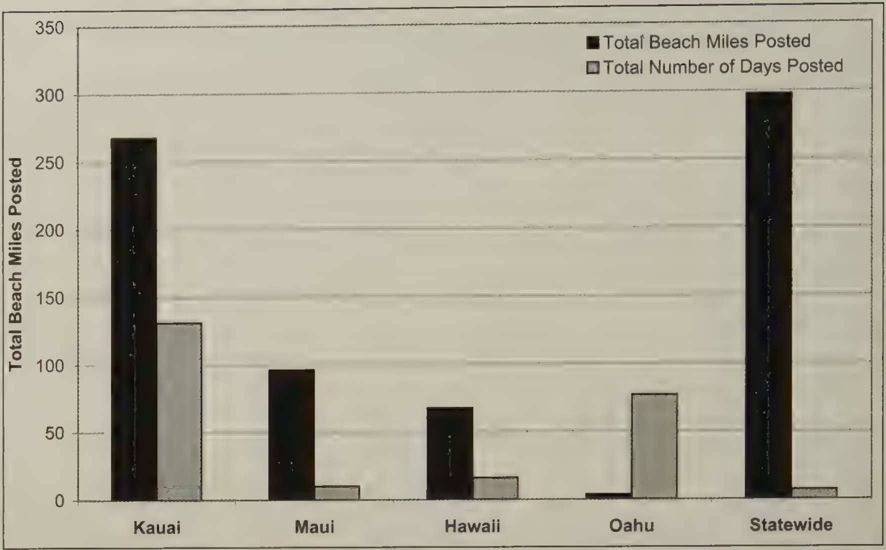


*Figure 8.31. Brown Water Advisories posted by the Hawaii DOH in 2006. Source: HIDOH, 2006.*

### USGS Monitoring

USGS completed an assessment of water quality of streams and groundwater on Oahu from 1999 to 2001 (Anthony et al., 2004). They found toxic contaminants in streams that drain urban and agricultural lands, and in groundwater supplies (although few chemicals exceeded drinking water standards in groundwater). In Oahu's urban streams, some of the highest levels of termite treatment chemicals in the U.S. were reported. The USGS conducted no analyses in the marine environment where ocean mixing and dilution occur. Based on the USGS findings, screening of estuaries and coastal waters for toxic contaminants such as chlordane, dieldrin and diazinon is warranted. Sediment particles containing toxic contaminants are easily transported to the ocean in storm flows and may be deposited at stream mouths and on reef flats.

### Monitoring by Private Entities for Permit Condition

Offshore water quality data are collected through a multitude of water quality monitoring programs associated with permit requirements for specific activities. These include the assessment of point source discharges, such as sewage outfalls and cooling water discharges, required for NDPES permits. Results for NPDES permit monitoring are submitted to the HIDOH. Nonpoint source inputs from land-based sources, such as resorts and golf courses, are monitored through a variety of state and local permit requirements. Data generally include constituents listed in the State of Hawaii Water Quality Standards: dissolved inorganic nutrients (nitrate + nitrite [$NO_3^-$ + $NO_2^-$]), ammonium [$NH_4^+$], orthophosphate [$PO_{4+}^{3-}$], and silica [Si]), chlorophyll a, salinity, turbidity, pH, temperature and dissolved oxygen. In total, approximately 3,000 ocean water samples are analyzed annually by private entities as required by permit conditions. These permit-related data have not been synthesized by island or region into a comprehensive database or report.

### University of Hawaii Biogeochemistry Research

Kaneohe Bay remains a site of innovative work to establish the links between water quality and effects to reef communities. A team of scientists from the Department of Oceanography at the University of Hawaii at Manoa and from NOAA/Pacific Marine Environmental Laboratory in Seattle, Washington, is examining how changing water conditions, due to input of nutrient rich storm runoff and physical oceanographic processes, drive phytoplankton blooms and cause changes in the direction of $CO_2$ transport between the ocean and atmosphere. The biogeochemical and physical conditions of the water column on coral reefs in Southern Kaneohe Bay are being characterized by an instrument array called the Coral Reef Instrument Monitoring and $CO_2$ Platform (CRIMP-$CO_2$). It provides near real-time data at five to 10 minute intervals.

The CRIMP-$CO_2$ deployment in November 2005 coincided with a La Niña event that was marked by high intensity rainfall for more than forty days (February to April 2006). The effects of the extreme weather and physical forcing on the biogeochemistry of the bay during the winter-spring of 2006 were significant, leading to several large phytoplankton blooms and subsequent drawdown of nutrients and $CO_2$.

Extreme rain events in 2006 delivered large pulses of materials to Kaneohe Bay that increased available nutrients from approximately 0.03 μM dissolved inorganic nitrogen (DIN) and approximately 0.02 μM dissolved inorganic phosphorus (DIP) during background conditions to >34 μM DIN and >0.9 μM DIP in surface waters of the south bay. Sudden shifts in the DIN:DIP ratio (approximately 2-3 to >100 in some cases) in bay waters associated with these pulses triggered significant algal blooms evidenced by chlorophyll a concentrations reaching 10-12 mg/m$^3$ throughout large areas of the affected area. Increases in dissolved $O_2$ and a draw down of $CO_2$, commensurate with the nutrient inputs, were observed at CRIMP-$CO_2$ buoy (http://www.pmel.noaa.gov/co2/coastal/kbay/).

Data collected during two storm periods in winter 2006 indicate that South Kaneohe Bay waters switched from being a net source to a net sink of atmospheric $CO_2$ during these events. The sea to air flux was found to vary between extremes of approximately +0.4 and -0.3 mmol $CO_2$/m$^2$/hour during the winter season. Regardless of the large but generally short-lived deviations when the bay water acted as a sink for atmospheric $CO_2$, southern Kaneohe Bay remained a net source of $CO_2$ to the atmosphere throughout the period of December 2005 to January 2007.

## BENTHIC HABITATS

In 2003, NOAA's CCMA Biogeography Branch (CCMA-BB) produced shallow water benthic habitat maps covering 60% of the coastline of the MHI from aerial photographs and hyper-spectral imagery (Coyne et al., 2003). In 2007, CCMA-BB used IKONOS imagery to expand and update these shallow water benthic habitat maps to include the entire coastline of the MHI (Figure 8.32; http://ccma.nos.noaa.gov/ecosystems/coralreef/main8hi_mapping.html). Other types of shallow water and coastline data (e.g., LIDAR bathymetric data, aerial photography, shoreline imagery) are available for download from the University of Hawaii's Coastal Geology Group at http://www.soest.hawaii.edu/coasts/data/index.html.

Since the late 1980s, multibeam bathymetric data have been collected in the MHI by numerous ships and organizations. These data have been synthesized into a 50 m gridded bathymetric map by scientists at the University of Hawaii's School of Ocean and Earth Science and Technology.

In 2005 and 2006, the PIFSC-CRED program surveyed 2,688 km$^2$ of seafloor in 10 to 1,000 m water depths in the MHI. Multibeam data collection efforts at Niihau, Penguin Bank, N. Molokai and the Kohala Coast of the Big Island concentrated on shallow environments <100 m. Penguin Bank, a large bank on the southwest side of Molokai, lies in water depths between 15 and 100 m and is the only large, flat, submerged bank in the MHI. Multibeam bathymetric data from Penguin Bank shows a mostly flat banktop with limited complex areas associated with sand waves and dunes and only a few near-shore features that may be associated with coral (Figure 8.33). Although the multibeam bathymetry and derived products show a flat, somewhat uninteresting banktop, the Penguin Bank backscatter data reveals the presence of more complex structures (Figure 8.33).

Since 1998, several large-scale monitoring programs have been initiated around Hawaii to address different issues concerning the condition of coral reef ecosystems (Table 8.10). A meta-analysis was conducted of the most spatially diverse programs, Coral Reef Assessment and Monitoring (CRAMP)/DAR, PIFSC-CRED, Fish Habitat Utilizations Study (FHUS) and West Hawaiian Aquariumfish Project (WHAP), to obtain an assessment of the coral reef assemblage around the MHI. CRAMP/DAR focused on a comprehensive description of the spatial differences and the temporal changes in coral reef communities in the MHI. PIFSC-CRED surveyed reefs that were wave exposed and otherwise difficult to access with the shore-based small craft used by other monitoring programs (e.g., CRAMP/DAR, WHAP). FHUS examined the efficacy of marine protected areas in Hawaii in terms of fish assemblages and benthic habitat characteristics. WHAP investigated reef areas targeted by the aquarium trade along the West Hawaii coastline.

### Spatial Assessment Methods

#### *CRAMP/DAR*

Fixed transects and fixed photoquadrats were surveyed at two reef areas, a shallow (about 3 m) and a deep (about 10 m) station at each of 30 state-wide sites at least twice since 1999. Total mean percent coral cover by station, mean percent coral cover by species within a station and species richness were documented. The monitoring site data were supplemented in the spatial dimension by a rapid assessment technique. Detailed methods are provided in Friedlander et al. (2003), Brown et al. (2004) and Jokiel et al. (2004). A total of 692 transects were surveyed across the state using these methods.

#### PIFSC-*CRED*

In 2005, benthic surveys were conducted around the MHI at a total of 72 sites, with two 25-m transect lines laid at each site. In 2006, an additional 36 sites were surveyed and 17 sites were revisited, totaling 108 unique sites. Video transects were recorded along transect lines as a durable record. The line-intercept method was used to quantify substrate composition at 0.5 m intervals. All corals whose center fell within 0.5 m on each side of the transect lines were enumerated by species and assigned to one of seven size classes based upon maximum colony diameter: <5 cm, 5-10 cm, 10-20 cm, 20-40 cm, 40-80 cm 80-160 cm, >160 cm (Kenyon et al. 2006b). Percent coral cover, richness, relative abundance, colony density, and size-frequency distributions were derived. Directed observations on coral disease, predation and bleaching were conducted along the same transect lines.

#### *FHUS*

Sampling was conducted in all 11 marine life conservation districts (MLCDs), the University of Hawaii Marine Laboratory Refuge, and adjacent habitats from 2002 to 2004 (Friedlander et al., 2006, 2007a, 2007b). In addition, marine areas adjacent to four national parks were surveyed in 2004 and 2005. Locations of assessment sites were determined using a stratified random sampling approach by four major habitat strata (colonized hard bottom, uncolonized hard bottom, unconsolidated sediment and macroalgae). Within each major habitat type, sampling was further stratified by management regime (MLCD and MLR, Fisheries Management Area, or FMA, and open access). Only hard bottom habitats were used in this analysis (859 transects).

Benthic cover was assessed along a 25-m transect line. Each transect was stratified into 5 x 5 m segments, with *in situ* 1 m$^2$ visual quadrats randomly allocated within each segment. Twenty-five randomly selected intersections were marked on each quadrat grid and used for substrate identification. Each intersection was identified using substrate categories of sand, coralline algae, turf algae, macroalgae, and coral. Coral and macroinvertebrates were identified to species level and algae to genera. Percent cover values for each substrate category and coral species were derived by dividing the number of occupied points by the total number of intersections (25) within each quadrat.

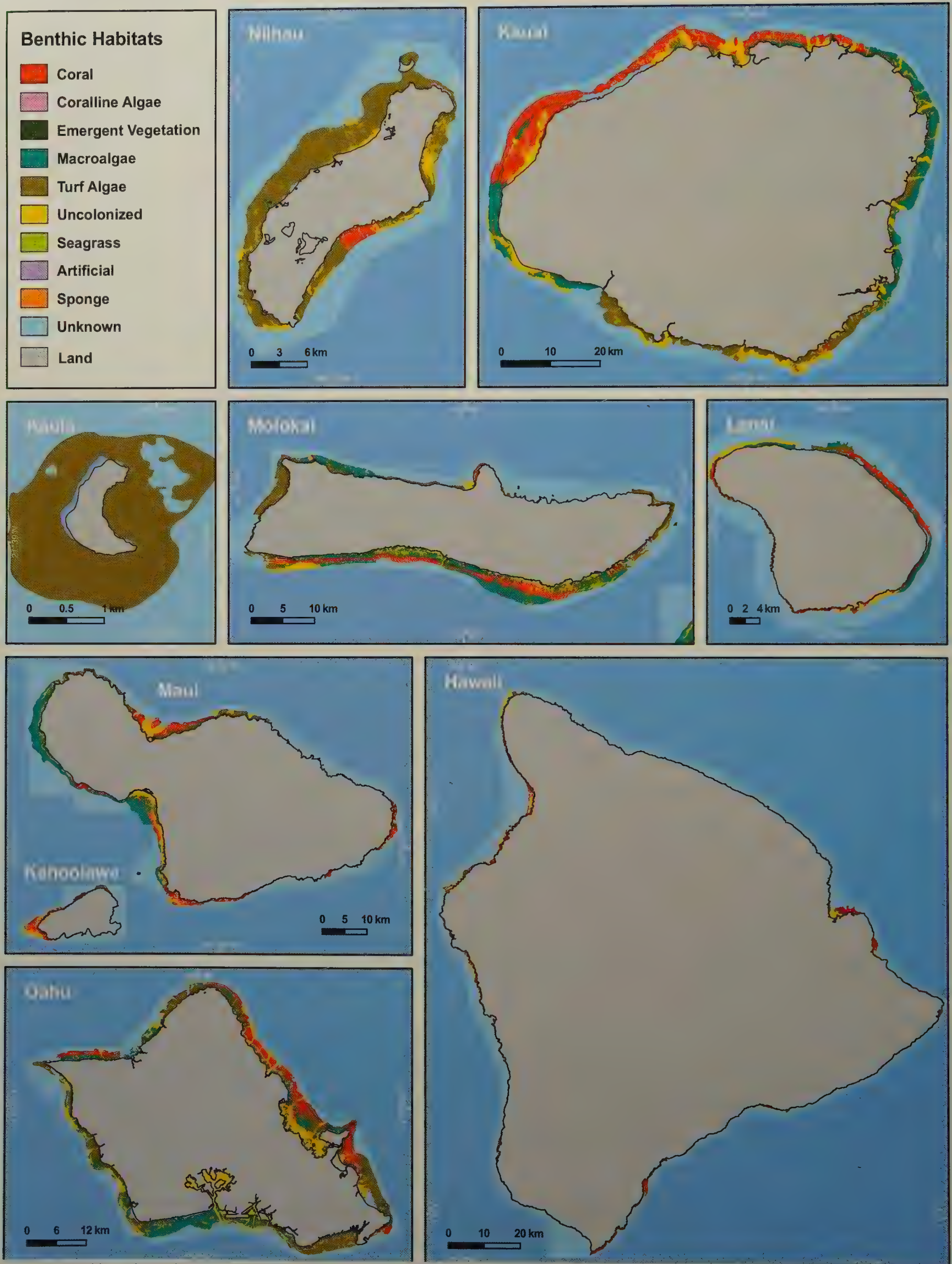

Benthic Habitats
Coral
Coralline Algae
Emergent Vegetation
Macroalgae
Turf Algae
Uncolonized
Seagrass
Artificial
Sponge
Unknown
Land
Niihau
0 3 6 km
Kauai
0 10 20 km
Kaula
0 0.5 1 km
Molokai
0 5 10 km
Lanai
0 2 4 km
Maui
Kahoolawe
0 5 10 km
Hawaii
0 10 20 km
Oahu
0 6 12 km

*Figure 8.32: Nearshore benthic habitat maps were developed by CCMA-BB based on visual interpretation of aerial photography and hyperspectral imagery. For more information visit http://ccma.nos.noaa.gov/ecosystems/coralreef/main8hi_mapping.html. Map: K. Buja.*

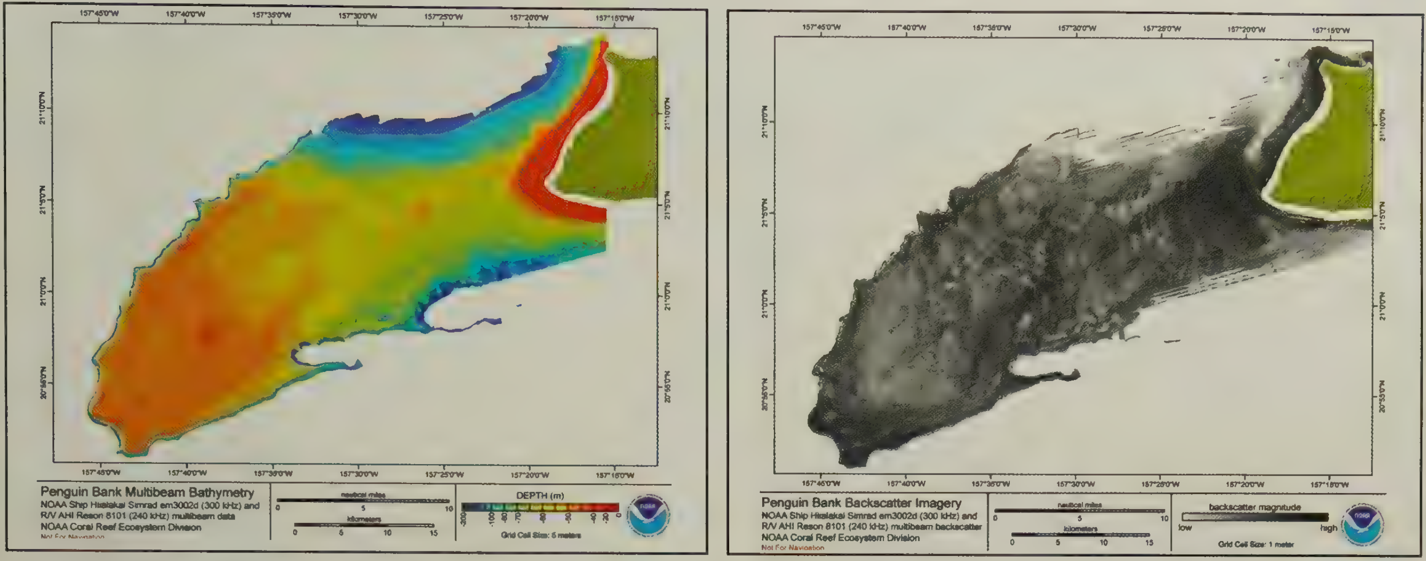

157°45'0"W
157°40'0"W
157°35'0"W
157°30'0"W
157°25'0"W
157°20'0"W
157°15'0"W
21°10'0"N
21°5'0"N
21°0'0"N
20°55'0"N
Penguin Bank Multibeam Bathymetry
NOAA Ship Hiialakai Simrad em3002d (300 kHz) and R/V AHI Reson 8101 (240 kHz) multibeam data
NOAA Coral Reef Ecosystem Division
Not For Navigation
nautical miles
0
5
10
kilometers
0
5
10
15
DEPTH (m)
-200
-100
-80
-70
-60
-50
-40
-30
0
Grid Cell Size: 5 meters
Penguin Bank Backscatter Imagery
NOAA Ship Hiialakai Simrad em3002d (300 kHz) and R/V AHI Reson 8101 (240 kHz) multibeam backscatter
NOAA Coral Reef Ecosystem Division
Not For Navigation
backscatter magnitude
low
high
Grid Cell Size: 1 meter

*Figure 8.33. Penguin Bank bathymetry and backscatter data. Source: PIFSC-CRED.*

### *WHAP*

The abundance of coral, macroalgae and other living substrata were estimated at 23 sites using a digital video camera along four 25 m transect at each site. Percentage cover estimates of substrate types were obtained from contiguous still frames using the program PointCount 1999. Tissot et al., (2004) provided detailed methods which were comparable to the CRAMP/DAR protocol outlined in Brown et al., (2004). Total coral cover was statistically similar among the reference, FMAs, and open access areas in depths ranging from 6-15 m. The new DAR Main Hawaiian Islands monitoring program has incorporated the various methods listed above into an integrated and comprehensive approach.

### *Results and Discussion*

Average coral cover across 1,682 independent transects/sites in the MHI was 19.9% ± 0.6% SE, with seven of the 29 coral species accounting for most of the cover (19.3%; Figure 8.34). The dominant species were: *Porites lobata* (8.5%), *Porites compressa* (3.8%), *Pocillopora meandrina* (2.5%), *Montipora capitata* (2.3%), *Montipora patula* (1.6%), *Montipora flabellata* (0.3%) and *Pavona varians* (0.3%). The remaining 22 species covered only 0.6% of the substrate.

Coral cover was highest in the southern portion of the archipelago (e.g., Molokini and Kahoolawe ) and lowest in the northern part (Table 8.12). Some exceptions did exist, such as the moderate coral cover at Kaula rock (23.5% ± 6.9% SE) and Hawaii (24.6% ± 0.9% SE), but in general coral cover decreased with increasing geologic age (r=-0.64).These results validate previous studies (e.g., Grigg, 1983; Jokiel et al., 2004) that have suggested this relationship, but with a considerably smaller sample size.

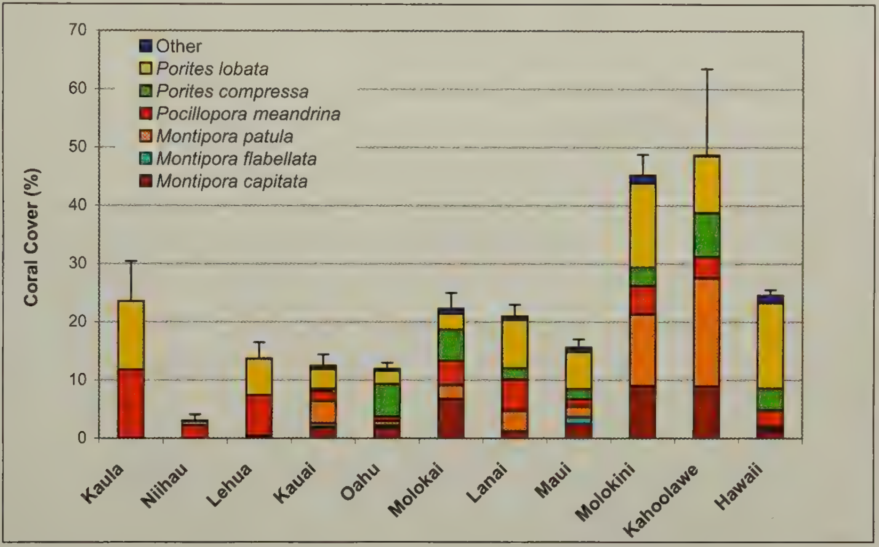


*Figure 8.34. Mean percent coral cover at each island in the MHI along a geological (longitudinal) gradient from oldest (west) to youngest (east). Coral cover was calculated from 1,682 transects/sites surveyed between 2001 and 2006. Data sources include CRAMP/DAR (n=692), PIFSC-CRED (n=108), FHUS (n=859) and WHAP (n=23). Mean percent cover ± 1 SE.*

*Table 8.12. Mean percent coral cover (± 1 SE) and sampling effort by island. N=number of independent sites sampled at each island. Islands ordered from oldest geologically (top) to youngest (bottom). Geologic ages from Clague and Dalrymple, 1987. Sources CRAMP/DAR, PIFSC-CRED, FHUS and WHAP.*

| ISLAND | MEAN CORAL COVER (%) | SAMPLING EFFORT (N) | GEOLOGIC AGE (MYA) |
|---|---|---|---|
| Kaula Rock | 23.5 ± 6.9 | 2 | 5.8 |
| Niihau | 3.0 ± 1.1 | 17 | 5.6 |
| Lehua | 13.7 ± 2.8 | 5 | 5.6 |
| Kauai | 12.5 ± 2.0 | 114 | 5.2 |
| Oahu | 11.9 ± 1.1 | 437 | 4.0 |
| Molokai | 22.3 ± 2.7 | 133 | 2.1 |
| Lanai | 21.0 ± 2.0 | 84 | 1.6 |
| Maui | 15.6 ± 1.4 | 254 | 1.3 |
| Molokini | 45.2 ± 3.6 | 63 | 1.0 |
| Kahoolawe | 48.7 ± 14.8 | 20 | 1.0 |
| Hawaii | 24.6 ± 0.9 | 553 | 0.6 |

Light and temperature conditions favorable to coral growth diminish with increasing latitude and increasing island age which helps explain the observed coral cover pattern.

There was also a negative correlation (-0.57) with mean species richness and geologic age of the islands. Sampling effort varied by island with some islands (e.g., Kahoolawe and Hawaii) under sampled compared to other islands (e.g., Molokini and Oahu; Table 8.12). Consequently, coral cover estimates by island will improve as programs extend their spatial coverage.

Waves appear to be the most important factor structuring coral reef assemblages in Hawaii (Grigg, 1983; Jokiel et al., 2004). Sites exposed to the larger west and northwest swells on the older islands (e.g., Kauai and Oahu) generally had lower coral cover (Figure 8.35), species richness and diversity (Jokiel et al., 2004). Storlazzi et al. (2005) showed that waves in Hawaii can reach destructive levels that will damage corals and restrict species distributions.

Another important factor influencing coral communities are anthropogenic activities that have been associated with the decline of coral reefs around the globe (Richmond, 1993). In Hawaii, the relationship of coral cover to human populations in the upland watershed indicated that larger populations generally had lower coral cover on the reefs adjacent to the watershed (Figure 8.36). Notable exceptions were found, however, including sites on patch reef crests in Kaneohe Bay with high coral cover (>90%) that are next to populated areas. In comparison, reefs fronting Honolulu and Waikiki beach were almost devoid of living corals (Mean 2.0 % ± 0.4% SE). Temporal patterns in coral cover at some of these sites can clarify anthropogenic impacts and reduce the location bias of humans choosing to settle near areas of good coral cover.

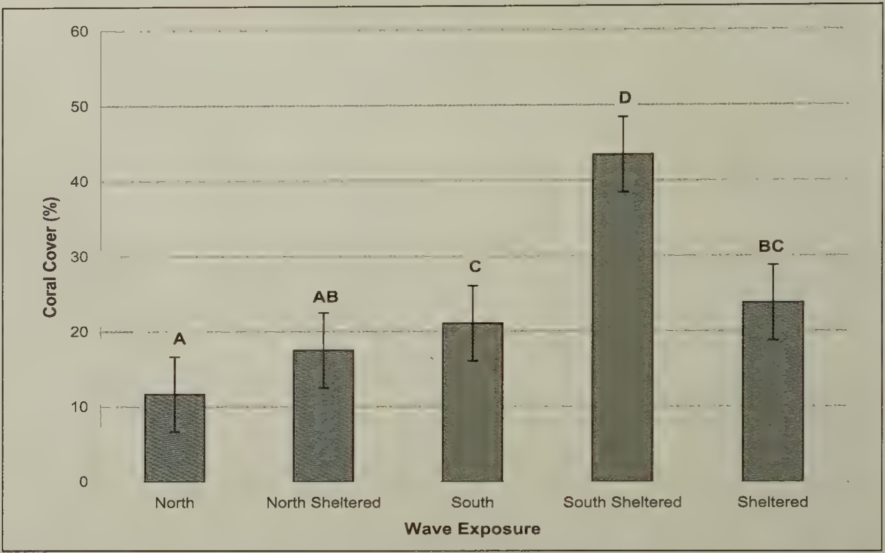


*Figure 8.35. Mean percent coral cover on hard bottom habitats in various wave exposure regimes in the MHI. Exposures with the same letter designation are not significantly different (Tukey's HSD multiple unplanned comparisons test, α=0.05). Wave exposure codes for each site were based on methods described in Friedlander et al. (2003). Error bars are standard error of the mean. Sources: CRAMP/DAR, PIFSC-CRED, FHUS, WHAP.*

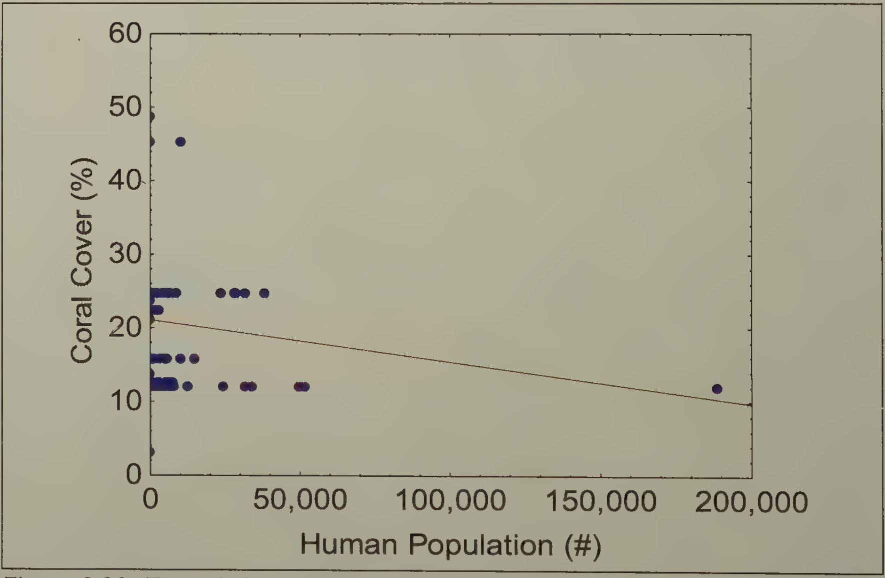


*Figure 8.36. The relationship of mean percent coral cover by island in the MHI to the human population within the adjacent watershed. Percent cover=21.1–0.00006*(human population), n=1,682, $r^2$= 0.11, p<0.001. Sources: CRAMP/DAR, PIFSC-CRED, FHUS and WHAP.*

## Long-Term Monitoring at Selected Sites

Sites in Hawaii that have been monitored over a longer time period (>10 years) are included for historical perspective (see Table 8.13). Coral cover has been surveyed sporadically over the years using different methods at each of the sites, but studies (i.e., Brown, 2004) comparing methods produced similar results both spatially and temporally.

The long-term trends at the selected sites show that the majority of the stations (19 out of 27) experienced a decline in percent coral cover over their respective study periods. Among islands with more than one long-term site, the change in coral cover was not significantly different ($F_{2,22}$=3.16, p=0.06, Figure 8.37). Several of these sites (e.g., Kahe Point and Pili o Kahe) have experienced cyclical changes in coral cover that can be explained by recruitment events among predominant corals (Coles and Brown, 2007). Possible explanations for the major declines (>10%) include reef slumping (e.g., Kaalaea and Jokiel et al., 2004), eutrophication (e.g., Kahekili; Smith et al., 2005) and sedimentation (e.g., Honolua Bay; Dollar and Grigg, 2004). Sites such as Hanauma Bay, Honolua Bay, Kahekili and Olowalu are high human use areas and changes at these reefs have important management implications. In addition, long-term data sets on coral cover are uncommon and provide benchmarks for changes in ecosystem components in Hawaii.

*Table 8.13. Average percent coral cover at selected sites that have been surveyed at time periods spanning 10 or more years. Overall percent change (Δ) from the initial survey to the last survey is shown in the last column. Data sources for each station are listed below. Asterisks (*) indicate sites within Kaneohe Bay.*

| | | | YEAR | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ISLAND | SIZE | DEPTH (M) | 71 | 74 | 75 | 76 | 79 | 81 | 82 | 83 | 84 | 85 | 86 | 87 | 88 | 89 | 90 | 91 | 92 | 93 | 94 | 95 | 96 | 97 | 98 | 99 | 00 | 01 | 02 | 03 | 04 | 05 | 06 | Δ |
| Kauai | Hanalei Bay[1,2,3] | 3 | | | | | | | | | | | | | | | | | | 15 | | | | | | 16 | 26 | | 17 | 17 | 7 | 5 | | -9 |
| | | 5 | | | | | | | | | | | | | | | | | | 6 | | | | | | 6 | | | | | 8 | 8 | | 2 |
| | | 7 | | | | | | | | | | | | | | | | | | 17 | | | | | | 23 | | | | | 23 | 16 | | -1 |
| | | 8 | | | | | | | | | | | | | | | | | | 20 | | | | | | 28 | 30 | | 26 | 36 | 29 | 29 | | 10 |
| | | 8 | | | | | | | | | | | | | | | | | | 8 | | | | | | 17 | | | | | 11 | 12 | | 4 |
| | | 14 | | | | | | | | | | | | | | | | | | 21 | | | | | | 17 | | | | | 25 | 19 | | -1 |
| | | 16 | | | | | | | | | | | | | | | | | | 15 | | | | | | 25 | | | | | 22 | 18 | | 3 |
| Oahu | Kahe Point[2,4] | 3 | | | | | | 20 | 19 | 16 | 16 | 16 | 19 | 22 | 20 | 18 | 17 | 12 | 10 | 5 | 5 | 5 | 5 | 9 | 7 | 9 | 13 | 15 | 17 | 17 | 8 | 6 | | -14 |
| Oahu | Pili o Kahe[2,4] | 3 | | | | | | 20 | 12 | 10 | 10 | 8 | 9 | 10 | 12 | 12 | 18 | 17 | 16 | 13 | 11 | 8 | 8 | 8 | 7 | 9 | 7 | 8 | 10 | 11 | 9 | 8 | | -12 |
| Oahu | Kaalaea[2,5,6]* | 2 | 92 | | | | | | | 82 | | | | | | | 79 | | | | | | | | | 62 | 51 | 49 | 67 | 59 | | 58 | | -35 |
| | | 8 | 7 | | | | | | | 11 | | | | | | | 9 | | | | | | | | | 3 | 2 | 4 | 3 | 3 | | | | -4 |
| Oahu | Heeia[2,5,6]* | 2 | 33 | | | | | | | 64 | | | | | | | 62 | | | | | | | | | 36 | 23 | 18 | 24 | 22 | | | | -11 |
| | | 8 | 1 | | | | | | | 15 | | | | | | | 2 | | | | | | | | | 8 | 7 | 7 | 5 | 7 | | | | 6 |
| Oahu | Moku o Loe[2,5,6]* | 2 | 6 | | | | | | | 45 | | | | | | | 21 | | | | | | | | | 30 | 20 | 16 | 13 | 14 | | | | 9 |
| | | 9 | 0 | | | | | | | 4 | | | | | | | 3 | | | | | | | | | 8 | 7 | 6 | 4 | 9 | | | | 9 |
| Oahu | Hanauma Bay[2,7,8] | 3 | | | | 28 | | | | | | | | | | | | | 47 | 28 | | 28 | | 28 | 33 | 24 | 26 | | 22 | | | | | -6 |
| | | 10 | | | | 38 | | | | | | | | | | | | | 40 | 36 | | 33 | | 32 | 25 | 27 | 27 | | 22 | | | | | -15 |
| Maui | Honolua Bay North[2,8,9,10,11,12] | 3 | | 39 | | | 23 | | | | | | | | | | | 51 | 56 | | 41 | 35 | 28 | 28 | 24 | 15 | 17 | 15 | 14 | 8 | 10 | 8 | 9 | -30 |
| | Honolua Bay South[2,8,9,10,11,12] | 3 | | 43 | | | 36 | | | | | | | | | | | | | | 42 | 42 | 38 | 33 | 28 | 21 | 27 | 23 | 24 | 21 | 23 | 11 | 9 | -34 |
| Maui | Kahekili[2,11] | | | | | | | | | | | | | | | | | | | | 52 | 42 | 51 | 42 | 49 | 44 | | 29 | 33 | 32 | 35 | 29 | 38 | -14 |
| | | | | | | | | | | | | | | | | | | | | | 58 | 45 | 50 | 56 | 51 | 30 | | 22 | 21 | 25 | 29 | 24 | 31 | -28 |
| Maui | Puamana[2,11] | 3 | | | | | | | | | | | | | | | | | | | 4 | 7 | 7 | 10 | 12 | 15 | 18 | 16 | 13 | 10 | 9 | | 10 | 6 |
| | | 13 | | | | | | | | | | | | | | | | 12 | 13 | 1 | 1 | 1 | 0 | 0 | 1 | 3 | 3 | 5 | 6 | 5 | 6 | 4 | 5 | -7 |
| Maui | Olowalu[2,11,13] | 3 | | | | | | | | | | | | | 31 | | | | | | 32 | 30 | 23 | 30 | 30 | 23 | 25 | 22 | 23 | 16 | 21 | 17 | 19 | -13 |
| | | 8 | | | | | | | | | | | | | | | | | | | 55 | 56 | 47 | 57 | 51 | 55 | 54 | 53 | 51 | 51 | 52 | 51 | 54 | -1 |
| Hawaii | Puako[8,14] | 3 | | | | | | | 66 | | | | | | | | | 42 | 42 | 43 | | 47 | | 58 | 60 | | | | | | | | | -5 |
| | | 10 | | | | | | | 63 | | | | | | | | | 46 | 41 | 43 | | 44 | | 59 | 45 | | | | | | | | | -18 |

**DATA SOURCES** [1] Friedlander et al., 1997; [2] Jokiel et al., 2004; [3] Friedlander and Brown, 2006; [4] Coles, 1998; [5] Maragos, 1972; [6] Hunter and Evans, 1995; [7] Anderson, 1978; [8] Hunter, 1999; [9] Environmental Consultants, 1974; [10] Torricer et al., 1979; [11] Brown, 2004; [12] Dollar and Grigg, 2004; [13] Ambrose et al., 1988 ; and [14] Hayes et al., 1982.

## *Halimeda* Meadows

*Halimeda kanaloana* is an endemic, calcified green alga forming expansive meadows over soft, sandy substrate in Hawaii. *H. kanaloana* meadows cover hundreds of kilometers of the sea floor around the Maui Nui island complex (Maui, Lanai, Molokai and Kahoolawe) from 10 to 90 m depths. Isolated patches have also been observed in south Oahu at 35 and 50 m depths. *H. kanaloana* meadows provide structural complexity up to 30 cm in height and often have densities of >250 individuals m$^2$. *H. kanaloana* and its associated epiphytic organisms may serve as a food source for other fish and invertebrates. For instance, large schools of predatory jacks have been observed preferentially foraging in *H. kanaloana* meadows from 30 to 60 m depths off west Maui (H. Spalding and F. Parrish, pers. obs.). Endangered hawksbill sea turtles forage for invertebrates found in this habitat. These meadows also provide habitat for cryptic sand-dwelling fish such as wrasses (Labridae), gobies (Gobiidae), eels (Congridae), pufferfishes (Tetraodontidae), boxfishes (Ostraciidae) and octopus (Octipodidae; F. Parrish, H. Spalding and R. Langston, pers. obs.).

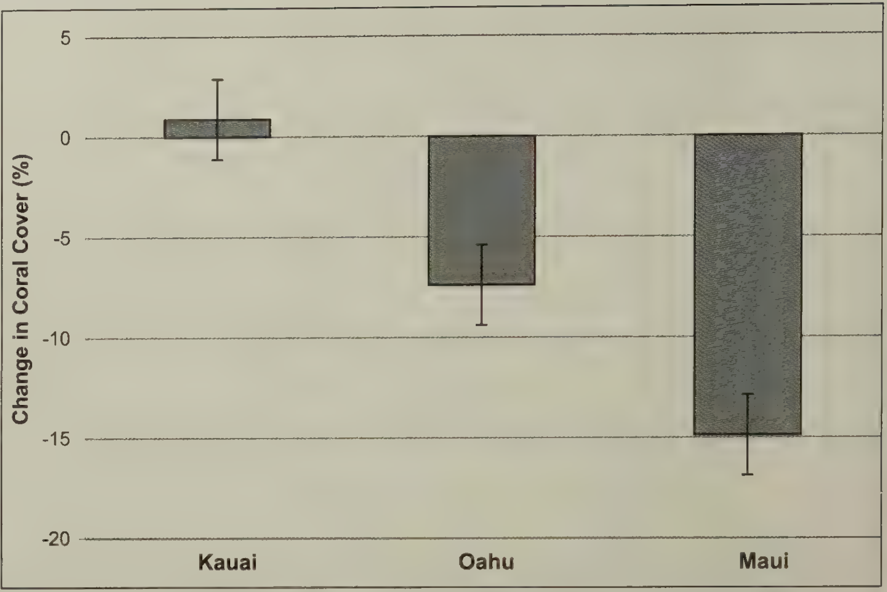


*Figure 8.37. Change in mean percent coral cover by island at long-term (>10 years) monitoring sites in the MHI. Error bars are standard error of the mean. Data sources in Table 8.13.*

Current research suggests that these meadows produce a large amount of sand for the Maui Nui island complex, with approximately 800 g of calcium carbonate produced per m$^2$ year. These meadows may be sensitive to repeated disturbances such as anchoring. *Halimeda* plants have the ability to quickly regrow within a few months from superficial scarring causing the removal of the upright plant body (thallus). However, if a disturbance causes the removal of the entire *Halimeda* holdfast, it may take many months to a year to regrow to original densities. *Halimeda* meadows in areas targeted for cruise ship anchoring may be particularly vulnerable.

## Deep Coral Reefs (30–100 m)

Hawaii has many unstudied coral reefs in deep water (30-100 m). Recently, reefs on Niihau (60-70 m), north Kauai (30-50 m), north Oahu (30-50 m; J. Rooney, pers. obs.), west Oahu (120 m; Pyle, pers obs.) and several areas around Maui Nui (30-100 m; T. Montgomery, pers. obs.) have been documented using drop cameras, ROVs, submersibles and mixed gas divers (Figure 8.38). These areas vary in species composition and biodiversity depending on location but often are comprised of high coral cover intermingled with macroalgae. Some sites are dominated by monospecfic stands of hermatypic corals (*Montipora* spp., *Porites* spp. and *Leptoseris* spp.). Recently, *Leptoseris* spp. was documented well below 100 m depth (Kahng and Maragos, 2006) and has been found to be a highly dominant genus in the 70–90 m range of Maui Nui. Macroalgae species may also play a significant role in these ecosystems (H. Spalding, pers. obs.). Little is known of the many potentially new species of invertebrates.

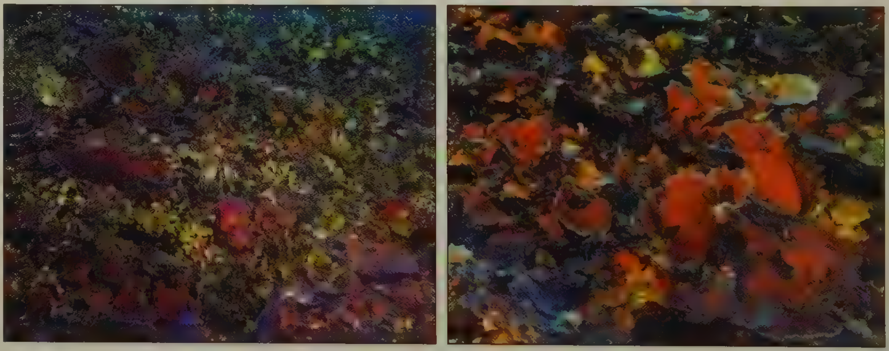


*Figure 8.38. Deep reefs off Maui at 70 m (left) and in the Auau Channel at 75 m (right). Photos: Hawaii Undersea Research Laboratory; T. Montgomery via a drop camera.*

# ASSOCIATED BIOLOGICAL COMMUNITIES

## *Comparison of Fish Biomass and Trophic Structure Among Islands*

Fish biomass by trophic group was examined across the major inhabited MHI. Data were complied from six comprehensive studies that surveyed fish at 188 locations with a total of 1,427 transects. Mean biomass by trophic group was calculated at each location and grand mean biomass by island was computed by weighting each location within an island by the number of transects conducted at each location.

The island of Niihau, including Lehua and Kaula rocks, are some of the most remote areas within the MHI and also had the highest fish biomass observed among the surveys (Figure 8.39). Although Molokai had the second highest biomass observed among islands, there were notable differences in biomass between the populated south shore and remote north shore areas. The south shore of the island experiences relatively high fishing pressure due to the subsistence community nearby. By contrast, the relatively remote north shore has high fish biomass and an abundance of apex predators as a result of lower human population density and seasonal refugia due to large waves which restrict fishing activities. The Big Island, as the name implies, has many remote locations relative to the overall human population and the reefs are healthy compared with the more densely populated areas of Oahu and Maui. Although parts of Maui suffer from overfishing and intense coastal development, there are a number of remote locations on the north and east shores that harbor healthy fish populations. Oahu had the lowest overall fish biomass among the populated islands and apex predators are virtually absent, likely due to intense fishing pressure.

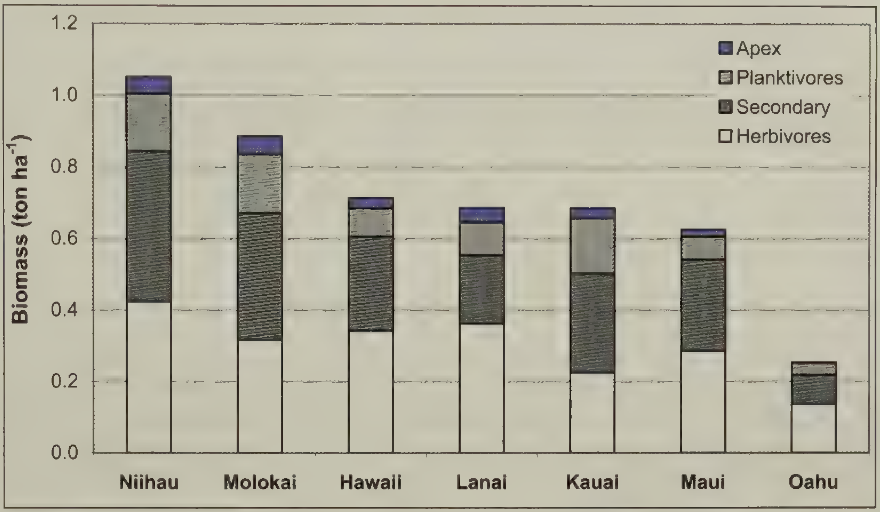


*Figure 8.39. Fish biomass (t ha$^{-1}$) among islands. Niiahu includes Lehua and Kaula rocks. Sources: CRAMP/DAR, PIFSC-CRED, FHUS and WHAP.*

## *Twenty Year Retrospective Study of Fish Populations at Honaunau, South Kona, Big Island*

Fish assemblages in three habitats at Honaunau, South Kona were surveyed over four summers in 1975 to 1978 and then resurveyed using identical methods in 1998 to 2001. In broad terms, assemblage structure was similar between survey periods (Table 8.14). The top four numerically dominant fish families (surgeonfish, damselfish, wrasse and butterflyfish) in 1975-1978 were also the most common families twenty years later.

*Table 8.14. Overall fish assemblage comparison at Honaunau. Source: DLNR/DAR*

| TOTAL # OF FISH SPECIES | 1975-1978 | 1998-2001 | %Δ | p |
|---|---|---|---|---|
| Total number fish species | 124 | 128 | ↑3.2 | |
| Mean number species/year | 92 | 90.8 | ↓1.3 | 0.39 |
| Mean number species/transect | 58.2 | 59.5 | ↑2.2 | 0.61 |
| Diversity (H') | 2.71 | 2.61 | ↓0.06 | 0.27 |
| Mean number fish/transect | 790.9 | 493.6 | ↓37.6 | 0.06 |
| **Total number transects** | **45** | **60** | | |

Nine of the 10 most abundant species in 1975-1978 were also among the 11 most abundant species in 1998-2001 (Table 8.15). There was a significant change in overall assemblage trophic structure (Figure 8.40; $x^2=24.99$, $p<0.001$) between the periods driven by significant deceases in the numbers of corallivores (-65%, $p<0.05$) and detritivores (-56%, $p<0.001$, t-tests). The later group consists primarily of a single very common species, the yellow eyed kole, *Ctenochaetus strigosus*.

*Table 8.15. Comparison of fish species abundance between survey periods. Asterisks (*) represent trends that are statistically significant at $\alpha = 0.05$. Source: DLNR/DAR.*

| SPECIES | HAWAIIAN/ COMMON NAME | 1975-1978 | 1998-2001 | %Δ |
|---|---|---|---|---|
| *Ctenochaetus strigosus* | Kole | 1 | 1 | ↓55* |
| *Zebrasoma flavescens* | Lauipala | 2 | 3 | ↓34 |
| *Chromis vanderbilti* | Blackfin chromis | 3 | 2 | ↓09 |
| *Acanthurus nigrofuscus* | Māiii | 4 | 5 | ↓34* |
| *Chaetodon multicinctus* | Kikakapu | 5 | 8 | ↓76* |
| *Thalassoma duperrey* | Hinalea lauwili | 6 | 6 | ↓44* |
| *Chromis agilis* | Agile chromis | 7 | 4 | ↑25 |
| *Paracirrhites arcatus* | Pilikoa | 8 | 9 | ↓40* |
| *Stegastes fasciolatus* | Pacific gregory | 9 | 11 | ↓53 |
| *Chromis hanui* | Chocolate-dip chromis | 10 | 29 | ↓88* |

The most substantial assemblage change was that overall mean fish abundance declined by 37% (p=0.06; Table 8.14). Various families of fishes responded differently; nearly all species of small bodied surgeonfishes, butterflyfishes and angelfishes de-

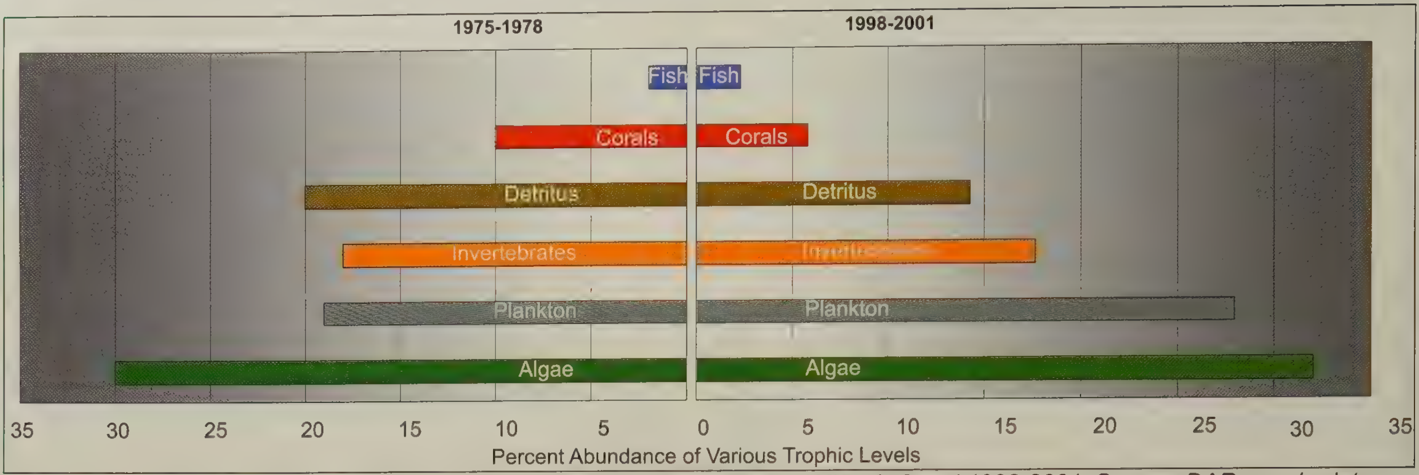


Figure 8.40. Comparison of Honaunau fish assemblage trophic structure in 1975-1978 and 1998-2001. Source: DAR unpub. data.

clined in abundance while other families, including typical food fishes such as parrotfishes (Scaridae) and soldierfishes (Myripristidae), increased. The increase in these latter species occurred during a period when the population of Hawaii County and the South Kona District increased respectively by 97% and 72%. Visitor counts at the adjacent Puuhonua o Honaunau National Historical Park also increased during this time by 18%. Based on information provided by area residents there is reason to believe that increased recreational use of the bay and adjacent shoreline by sunbathers, swimmers, snorkelers and divers may have reduced the level of fishing activities within the bay. Thus the increased abundance of certain food fishes may be in part related to a relaxation of fishing pressure.

Although three major storms influenced Honaunau between survey periods, the most recent benthic analysis indicated a healthy, vibrant reef system with high coral cover and high spatial complexity. Habitat alteration is thus unlikely to be a factor in the widespread decline of many smaller bodied fishes. Commercial aquarium fishing is however implicated in this decline (Figure 8.41). Of the 20 most collected aquarium species, 18 declined in abundance ($p<0.001$) with intensively collected species generally having experienced the greatest declines. Two collected species, blue stripe butterflyfish (*Chaetodon fremblii*) and bandit angelfish (*Apolemichthys arcuatus*) were repeatedly recorded during the 1975-1978 surveys but totally absent during 1998-2001 surveys.

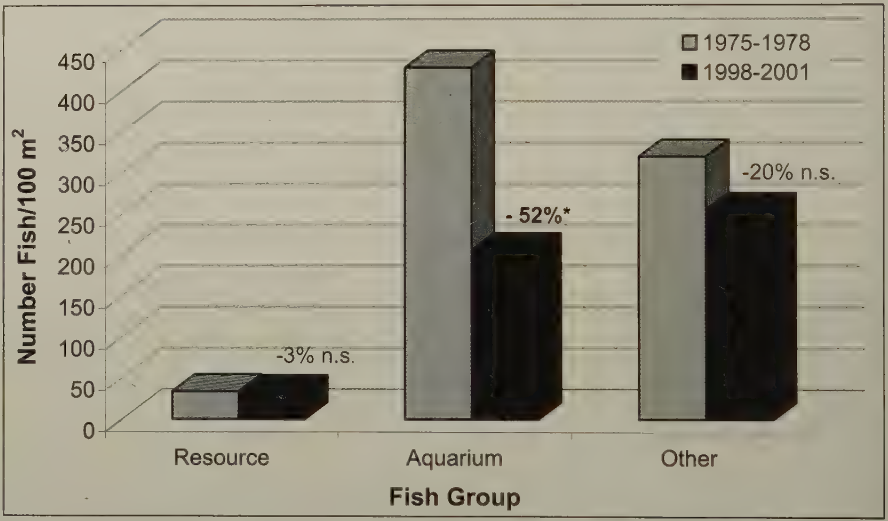


Figure 8.41. Comparison of various fish functional groups at Honaunau over two survey periods. Asterisk (*)=$p<0.05$, t-test. Source: DLNR/DAR.

In contrast to the aquarium species, there were no comparable consistent changes in other non- or less collected groups: 17 of 29 "food fishes" were lower while 12 were higher ($p=0.46$). For another 47 species regarded as neither food nor aquarium species, 26 declined while 21 became more abundant ($p=0.56$).The introduced peacock grouper, *Cephalopholis argus* (roi) was initially rare but increased 17-fold in the twenty years between survey periods (from 0.4 to 6.9 fish/1000 m$^2$). The potential impact of this increase on other species at Honaunau over this period is presently under evaluation.

### *Preliminary Assessments of Fish Stocks in the MHI*

Preliminary assessments for 55 fish species targeted in the commercial, recreational and ornamental fisheries within the MHI were developed by comparing their abundance to the Northwestern Hawaiian Islands Marine National Monument, a large, virtually unfished reference area. Underwater visual censuses were used to survey shallow-water reef fishes in the heavily fished MHI and in the NWHI (Sladek Nowlis et al., in review). Nearly three-quarters of the species examined in the main Hawaiian Islands appeared to be depleted (Figure 8.42). Large mobile predators were especially affected, but many other target and non-target species appeared to be in poor condition as well. When no-take areas in the MHI were used as a reference area, only 13% of the species appeared to be in poor condition, showing that these small no-fishing zones serve poorly as unfished reference areas, particularly for stocks in the worst condition. With the help of a larger and therefore more appropriate unfished reference area, there is strong evidence of negative ecological effects in Hawaiian shallow water reef assemblages that are likely caused by fishing. These preliminary assessments of individual stocks warrant further investigation before making a final assessment of the status of any the species involved.

By comparing size frequency distributions for certain species in the NWHI and MHI, natural and fishing mortality rates were developed. Since the NWHI populations experience little fishing pressure, those mortality rates represent natural mortality (M) while the MHI populations experience both natural and fishing mortality (F). Preliminary analysis of the blue trevally (*Caranx melampygus*) using mean observed sizes indicated that M is moderate, approximately 0.27, according to the estimated total mortality in the unfished NWHI (Figure 8.43). In the MHI, a total mortality rate was estimated at 0.69 and therefore an F of 0.42. It is common to use F30, a fishing mortality rate that allows a typical member of the population to produce 30% of its reproductive potential in the absence of fishing. For this species, F30 was estimated to be 0.22, suggesting that recent fishing rates were nearly twice a reasonable proxy for maximum sustainable yield. One measure of recent fishing is the current spawning potential ratio (Figure 8.42). This calculation indicates that blue trevally in MHI are currently only producing 11% of their reproductive potential. These results are consistent with analyses of the relative biomass densities of this species in the MHI and NWHI that indicated the MHI population may have dropped to 2% of its unfished abundance (Sladek Nowlis et al., in review).

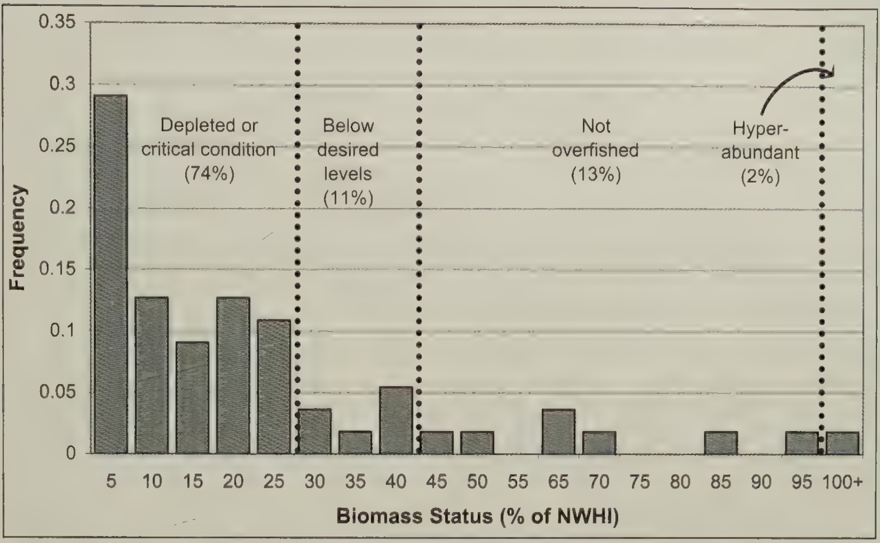


*Figure 8.42. Stock status of 55 species in the MHI compared to the NWHI as an unfished reference area. Source: Sladek Nowlis et al., in review.*

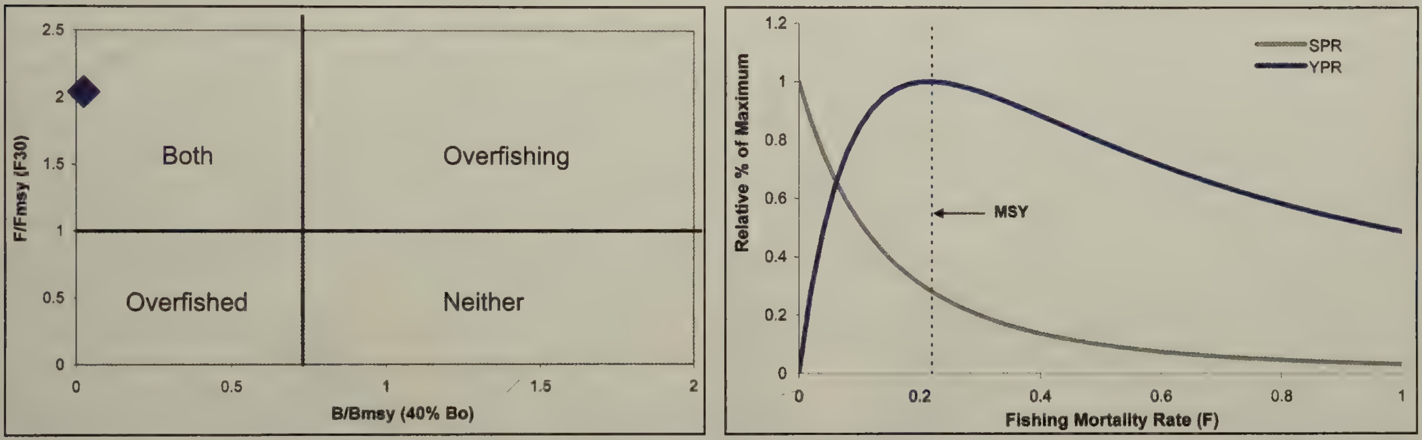


*Figure 8.43. Left panel shows fishing mortality rate (F), biomass estimates (B) and right panel shows spawning potential ratio (SPR), and yield per recruit (YPR) for blue trevally (*Caranx melampygus*). Source: Friedlander, unpub. data.*

### Resistance and Resilience In Hanalei Bay, Kauai Fish Assemblages Since 1992

A limited number of data sets exist in Hawaii to examine the resilience and resistance of coral reef ecosystems to natural disturbance. Hanalei Bay on the north shore of the island of Kauai has been monitored since 1992 providing a unique data set in which to examine changes in the composition of the coral reef community over time (Friedlander et al., 1997; Friedlander and Brown, 2006). Hanalei Bay is directly exposed to large winter swells with high surf, as well as frequent heavy winter rainfall and high river discharge.

From 1991 to 1994, an extensive marine resource assessment was conducted in Hanalei Bay to characterize benthic habitat types, examine the spatial and temporal distribution of the marine biota, and describe the fishery within the bay (Friedlander and Parrish,1997; Friedlander and Parrish, 1998a and 1998b). Permanent sites were resurveyed in 1999, 2003, 2004 and 2005 to examine the temporal dynamics in coral reef community structure in Hanalei Bay since 1992.

Reef fishes in Hanalei Bay demonstrate distinct assemblage structures and characteristics based on hardbottom habitat type. The highest number of fish species was associated with deeper habitats that had high structural complexity. Low numbers of species were observed on reef flats that were distant from sand areas and had low habitat relief.

Certain habitats changed more dramatically than others from 1992 to 2005 and had clearly separate faunal assemblages. An ordination plot showed the deep slope habitat and the spur and groove habitats had high concordance among years (Figure 8.44). In contrast, the low relief and shallow slope habitats showed more dramatic changes among years but the assemblage in more recent years shows similarly with 1993 and 1994. This plot highlights the resistance of deeper and more complex habitats to interannual variability. While the low relief and shallow habitat types are more variable, they show resilience.

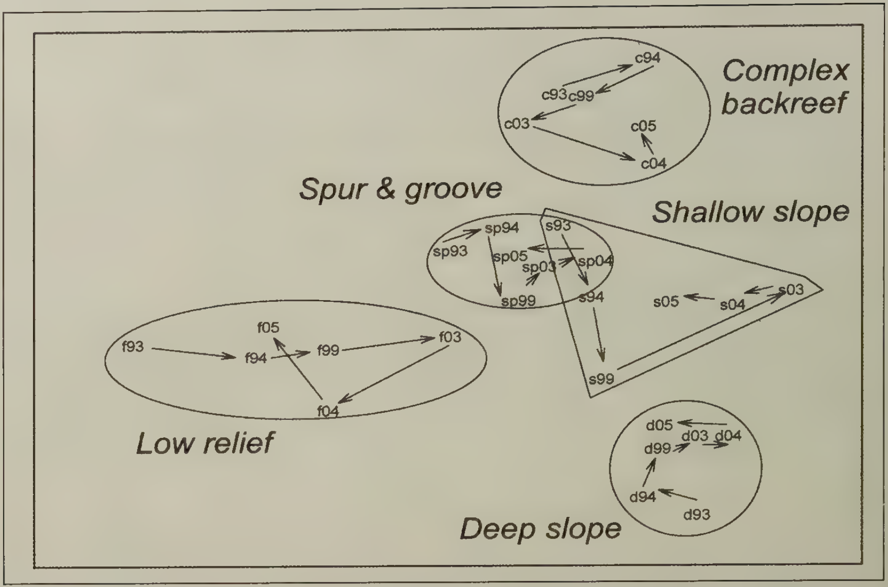


*Figure 8.44. Hanalei Bay fish assemblage (number of individuals) changes over time in various habitat types. Source: Friedlander and Brown, in review.*

## CURRENT CONSERVATION MANAGEMENT ACTIVITIES

### Hawaii's Marine Protected Areas

Within the MHI, there are 34 state-managed areas which limit fishing activities in nearshore marine waters: 11 MLCDs (areas designed to conserve and replenish marine life), 20 FMAs (areas designed to resolve conflicts among users, including fishers), and three other marine managed areas: Ahihi-Kinau Natural Area Reserve (NAR), Kahoolawe Island Reserve and Coconut Island Hawaii Marine Laboratory Refuge (HMLR). In addition, members of the public have limited or no access to the shoreline and nearshore waters within and around military or security areas on Oahu and Kauai (Pearl Harbor, Kaneohe Bay Marine Corps Base Hawaii, Barking Sands Pacific Missile Range Facility and Honolulu Reef Runway) or in the Hawaii Volcanoes National Park.

The large number of restricted-access or restricted-fishing areas in the MHI gives the impression of a substantial network of actively managed and protected marine areas, but the reality is that the majority of those areas are small and, nearly all allow some or several forms of fishing within their boundaries; some types of fishing are even permitted within six of the 11 MLCDs. In total, only 0.4% of nearshore MHI waters <60 ft deep (an approximation of the inshore habitats which are the primary targets for fishing of reef and reef-associated species) are in no-take MPAs (Figure 8.45). An additional 3.6% are in partially protected areas, and 6.5% are in areas with no access or restricted access to members of the public. The remaining 89.5% of nearshore waters are not spatially managed for fishing or specially restricted.

The proportion of nearshore MHI waters in no- and negligible-take areas including fully protected MLCDs, extremely limited access reserves and no-access zones is only 4.8% (Table 8.16). The large majority of that is in military and security no-access zones on Oahu and Kauai or in the Kahoolawe Island Reserve, and so the extent of complete no-take areas on other islands is extremely limited: only 1.7% of nearshore habitat around Maui Island and 0.2% around Hawaii Island.

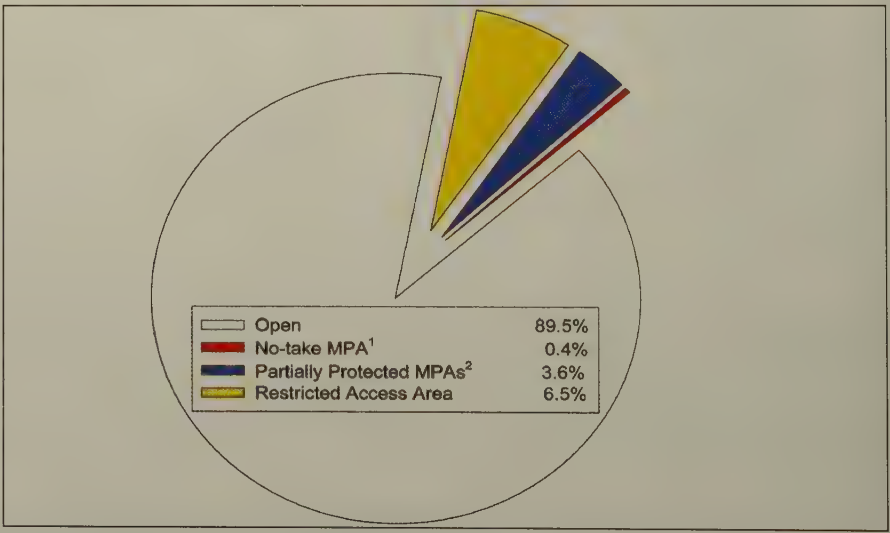


*Figure 8.45. MMAs and restricted-access areas by management category (<60 ft deep nearshore marine areas) in the MHI.* ***Notes: (1)*** *no-take portions of MLCDs, plus Ahihi-Kinau NAR and Coconut Island HMLR;* ***(2)*** *mostly FMAs and portions of MLCDs where some fishing is allowed, plus various harbors, wharfs and piers;* ***(3)*** *Military and security zones with no access to the public (total of 2.7%), with access by permits which require background security checks (total of 1.6%), Kahoolawe Island Reserve (1.7%) which limits access to the public and allows subsistence fishing by permit only, and Hawaii Volcanoes National Park (0.5%), in which shoreline fishing is restricted to native Hawaiians and their guests. Source: DLNR/DAR, unpub. data.*

Outside of those no-access or no-take areas there are only limited additional restrictions on most fishing gears. Therefore, the great majority of MHI nearshore waters are open to common recreational fishing gears: for pole and line 94.7%, for throw-net 94.4%; and for spearfishing 94.9% of nearshore waters are open (see Table 8.16). Prohibitions on other gears are more extensive: 8.0% of nearshore waters are closed to aquarium-fish collecting, and 27.5% are currently closed to lay-gillnet fishing. The percentage of nearshore waters closed to lay-gillnet fishing increased by nearly 20% in March 2007, when lay-gillnet restrictions were enacted on portions of south/southeast Oahu and on the whole of Maui Island.

*Table 8.16. Area closure by management type and type of fishing. Source: DLNR/DAR, unpub. data.*

| | CLOSED | OPEN |
|---|---|---|
| State managed no-take areas[1] | 0.4 % | |
| State-managed areas with severely limited access[2] | 1.7 % | |
| Military/Security no-access areas | 2.7 % | |
| **TOTAL – all fishing or access prohibited or heavily restricted** | **4.8 %** | **95.2 %** |
| **Area restrictions by fishing gear (including areas above)[3]** | | |
| Lay gillnet | 27.5 % | 72.5 % |
| Throw-net | 5.6 % | 94.4 % |
| Pole and line | 5.3 % | 94.7 % |
| Spear-fishing | 5.1 % | 94.9 % |
| Aquarium-fish collecting | 8.0 % | 92.0 % |

**Notes: (1)** no-take portions of MLCDs, plus Ahihi-Kinau NAR & Coconut Island HMLR **(2)** Kahoolawe Island Reserve **(3)** 1.6% of near-shore waters are in military-restricted access areas (Kaneohe Bay MCBH & southern portion of Barking Sands PMRF) where only active duty servicemen or locals with permits may fish, and 0.5% in the Volcanoes National Park, where only native Hawaiians and guests may fish from shore. For purposes of above calculations, military and security access areas accessible by permit are considered open to fishing, but Hawaii Volcanoes is considered closed to predominantly shoreline gears: pole & line and throw-net.

*Evaluation of Marine Protected Area (MPA) Efficacy*

Hawaii has developed a system of eleven Marine Life Conservation Districts (MLCDs) to conserve and replenish marine resources around the state that vary in size, habitat quality and management regimes, providing an excellent opportunity to test hypotheses concerning MPA design and function using multiple discreet sampling units. NOAA's Digital benthic habitat maps for all MLCDs and adjacent habitats were used to evaluate the efficacy of existing MLCDs using a spatially-explicit stratified random sampling design (Friedlander et al., 2006; 2007a and 2007b). Results showed that a number of fish assemblage characteristics (e.g., species richness, biomass, diversity) vary among habitat types, but were significantly higher in MLCDs compared with adjacent fished areas across all habitat types. Overall fish biomass and the number of large fishes (>20 cm) was greater than adjacent areas open to fishing by more than 200% and 150%, respectively (Figure 8.46). Areas on Oahu and Maui showed the largest differences between MPAs and fished areas, presumably due to higher fishing pressure and poorer habitat quality associated with the areas (Figure 8.47).

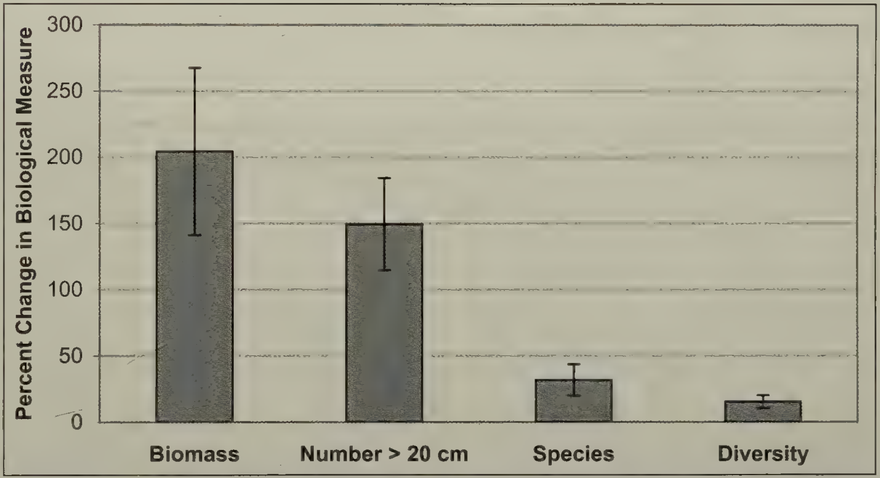


*Figure 8.46. Percent change in biological measures between MLCDs and adjacent areas open to fishing. Values are means and standard error. Source: Adapted from Friedlander et al., 2007a*

In addition, apex predators and other resource species were more abundant and larger in the MLCDs, illustrating the effectiveness of these closures in conserving fish populations within their boundaries. Based on biomass ratios inside and outside MLCDs, all protected areas appear to conserve fish biomass, in varying degrees, within their borders compared to adjacent areas open to fishing. Habitat type, protected area size and level of protection from fishing were all important determinates of MLCD effectiveness with respect to their associated fish assemblages. Although size of these protected areas was positively correlated with a number of fish assemblage characteristics, all appear too small to have any measurable influence on the adjacent fished areas. These protected areas were not designed for biodiversity conservation or fisheries enhancement yet still provide varying degrees of protection for fish populations within their boundaries. Implementing this type of biogeographic process, using remote sensing technology and sampling across the range of habitats present within the seascape, provides a robust evaluation of existing MPAs and helps define ecologically relevant boundaries for future MPAs.

### *Effectiveness of a MPA Network to Manage the West Hawaii Aquarium Fishery*

The aquarium collecting industry in Hawaii and especially West Hawaii has long been a subject of concern and controversy. Growing public perception of dwindling fish stocks due to over-collecting eventually developed into a severe multiple use conflict with particular animosity between aquarium collectors and the dive tour industry. In January 2000, a network of nine Fish Replenishment Areas (FRAs) which prohibit aquarium collecting was established in West Hawaii to address declines of aquarium-collected reef fishes and escalating conflict. FRAs comprise 35.2% of the coastline and were designated with substantial community input.

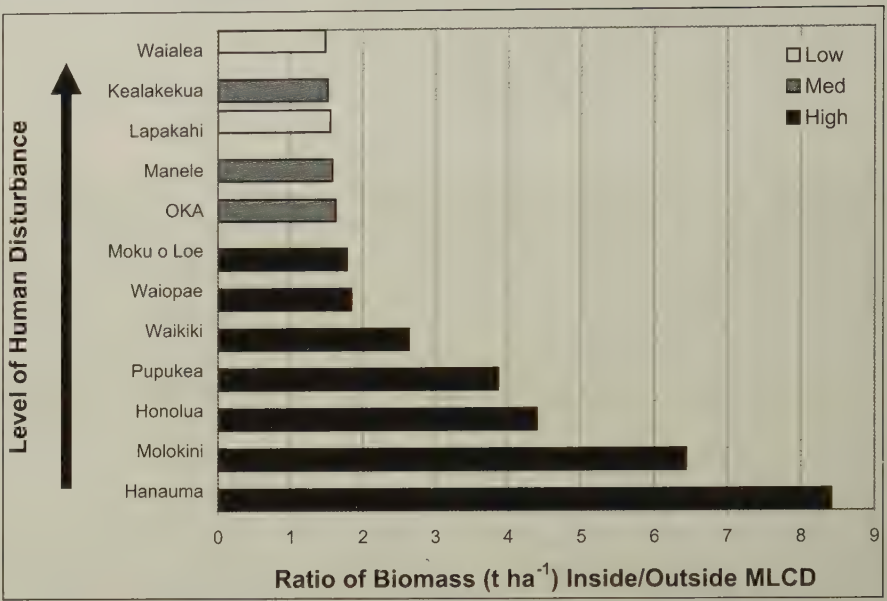


*Figure 8.47. Ratio of biomass (t ha$^{-1}$) inside MLCDs and Moku o Loe Refuge versus outside areas open to fishing. Hardbottom habitats only. Source: Friedlander et al., 2007.*

To assess the effectiveness of the FRA network and its impact on the aquarium fishery a multi-agency monitoring effort, called WHAP, was undertaken. Since 2005, monitoring has been undertaken by DAR alone. WHAP employed a Before-After-Control-Impact Design which compares fish densities in FRA sites before and after closure to densities in sites not subject to fish collecting ("control" areas). Seven years after closure of the FRAs, eight of the 10 most heavily collected species (representing 97% of all collected fishes) increased in density relative to control areas, three of those increases being statistically significant (Table 8.17), and the number one collected species, which comprises approximately 80% of the total catch, yellow tang (*Zebrasoma flavescens*), increased by 103% in absolute terms, and 54% relative to control sites. Only one species, the multiband butterflyfish (*Chaetodon multicinctus*) declined significantly in abundance in FRAs relative to control areas.

*Table 8.17. Changes in abundance of 10 most collected aquarium species at nine monitoring stations in FRAs in West Hawaii. Species ordered by total reported catch in years 1999 to 2006. FRAs were closed to aquarium collecting in 2000. Source: DLNR/DAR.*

| COMMON NAME | SCIENTIFIC NAME | MEAN DENSITY (#/100 m$^2$) | | OVERALL % CHANGE IN DENSITY | R$^3$ |
|---|---|---|---|---|---|
| | | Before[1] | After[2] | | |
| Yellow tang | *Zebrasoma flavescens* | 14.7 | 30.0 | +103% | **+53%*** |
| Kole | *Ctenochaetus strigosus* | 31.0 | 37.5 | +21% | +03% |
| Achilles tang | *Acanthurus achilles* | 0.24 | 0.15 | -38% | +03% |
| Clown tang | *Naso lituratus* | 0.75 | 0.94 | +26% | +08% |
| Chevron tang | *Ctenochaetus hawaiiensis* | 0.23 | 0.39 | +71% | **+74%*** |
| Forcepsfish | *Forcipiger flavissimus* | 0.50 | 0.57 | +15% | **+41%*** |
| Fourspot butterflyfish | *Chaetodon quadrimaculatus* | 0.03 | 0.09 | +168% | +18% |
| Ornate wrasse | *Halichoeres ornatissimus* | 0.94 | 0.73 | -22% | -09% |
| Multiband butterflyfish | *Chaetodon multicinctus* | 5.7 | 4.7 | -17% | **-27%*** |
| Hawaiian cleaner wrasse | *Labroides phthirophagus* | 0.88 | 0.47 | -47% | +2% |

**Notes: (1)** "Before" densities are densities before establishment of reserve network; **(2)** "After" densities represent average density over 2005/2006; **(3)** "R" represents change in density within FRAs relative to 'control' sites, e.g., to sites which were already protected in 1999 and whose status did not change over the period we have data from. An R value was calculated separately for each species in each of the nine surveyed FRAs (R in each case being change in that FRA relative to mean chance in control areas). R values displayed are the mean R/species. *R values are considered significant at alpha of 0.1, when 90% confidence intervals of the mean of R does not overlap zero.

The effect of the FRAs on the aquarium fishery itself has been positive. Compared to before the establishment of the FRAs, there are now substantially more collectors working in the fishery (Figure 8.48), and the total number of fish caught and the total value of the fishery are approximately twice what they were prior to creation of the reserve network (Figures 8.48 and 8.49). Compliance by collectors to the FRAs has generally been good and incidents of harassment and conflict between collectors and other ocean users has been markedly reduced.

The increased densities of aquarium fishes in FRAs, and especially of the yellow tang, indicate that the FRAs have been effective at replenishing aquarium fish stocks in West Hawaii after seven years of closure. Additionally, the results of this ongoing study demonstrate that, to date, the fishery has dramatically improved since the establishment of the West Hawaii FRAs. Moreover, the existence of the FRA network has resulted in reduced conflicts, greater public support for management, and better enforcement of regulations.

*Spillover from West Hawaii MPA Network*

Due to the lack of fishery mortality of large individuals of the primary aquarium target species, yellow tang, (adults are too large for aquarium collecting, and it is not a desired food fish), it is an ideal species for examining spillover in an MPA network. Recruit yellow tangs preferentially settle out in mid-depth reef areas dominated by finger coral, *Porites compressa*, but move to shallower nearshore habitats upon reaching sexual maturity at around 3-4 years of age (J. Claisse, pers. comm.). By surveying shallow water stocks of this species it is possible to get a reasonable measure of total reproductive stock size.

A specialized type of fish survey was undertaken to assess adult stocks of yellow tang both within the reserves and in outside areas. These surveys utilized a diver propulsion device termed "Jetboots", which consist of leg mounted propulsive units and a tank mounted battery pack (Figure 8.50).

Each survey consisted of a timed 18 minute transect in which fish within a 5 m wide belt were counted. Sixteen sites along the West Hawaii coastline were surveyed five times each. The sites surveyed were in three general locations; one set was within protected areas closed to aquarium collecting, another group was close to the borders of protected areas (within 2 km of nearest boundary) and the third was in areas open to harvesting and >2 km from the nearest reserve boundary.

Adult yellow tang populations at most Jetboots survey sites were high (>20 /100 m$^2$, Figure 8.51). There was also a generalized pattern for higher abundance within protected areas and fewer adult yellow tangs in open areas, indicating that the MPA network has increased breeding stocks within reserve boundaries. Open sites close to boundaries tended to have intermediate numbers of yellow tangs, strongly suggestive of spill-over of adults from the protected areas. Mean ± SE densities per 100 m$^2$ in areas within different categories were: FRAs (aquarium closed areas) 26.3 ± 0.8% SE; MPAs (long-term protected) 22.5 ± 1.4% SE; boundary sites (<2 km from reserve boundaries) 25.1 ± 3.6% SE; and open sites >2 km from nearest reserve boundary 17.8 ± 2.4% SE. Anomalous sites either

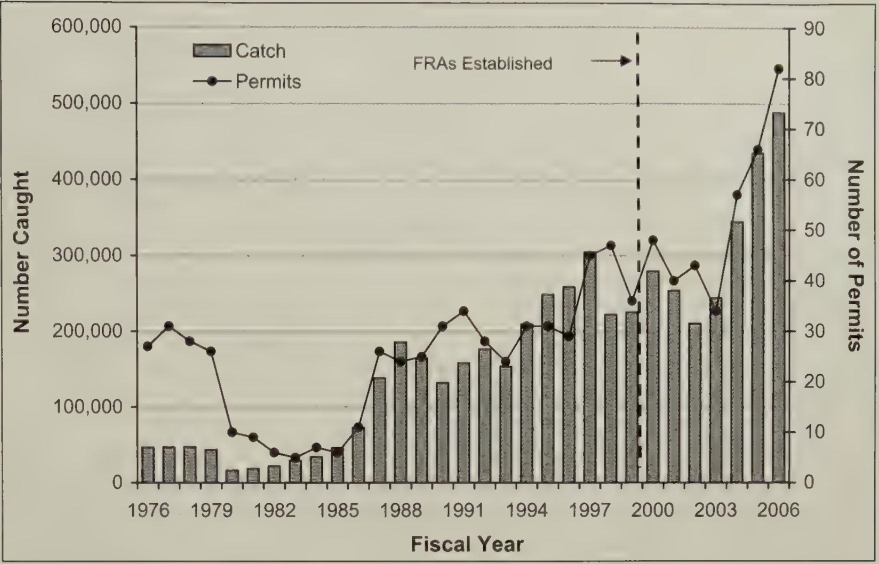


*Figure 8.48. Number of aquarium permits and number of collected animals in west Hawaii from 1976 to 2006. Source: DLNR/DAR.*

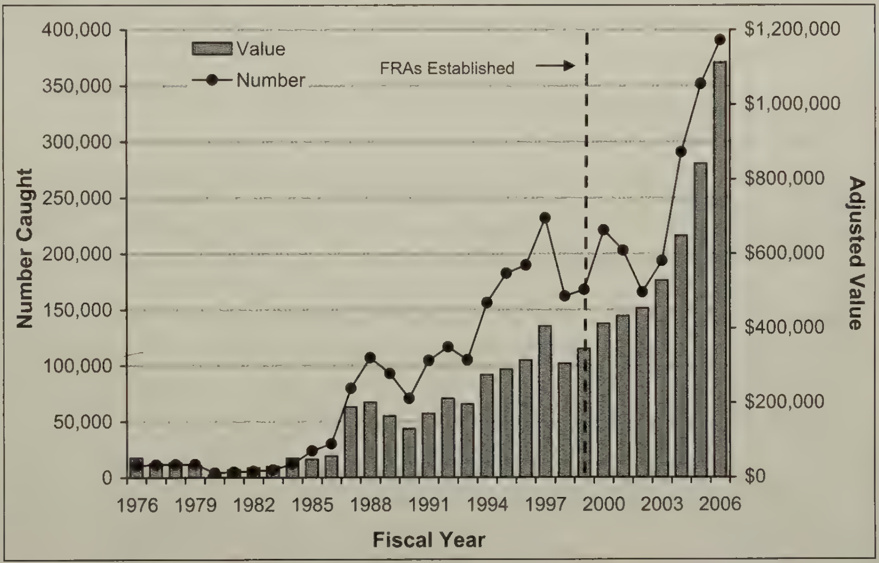


*Figure 8.49. Number and value of yellow tang caught in the west Hawaii aquarium fishery from 1976 to 2006. Source: DLNR/DAR.*

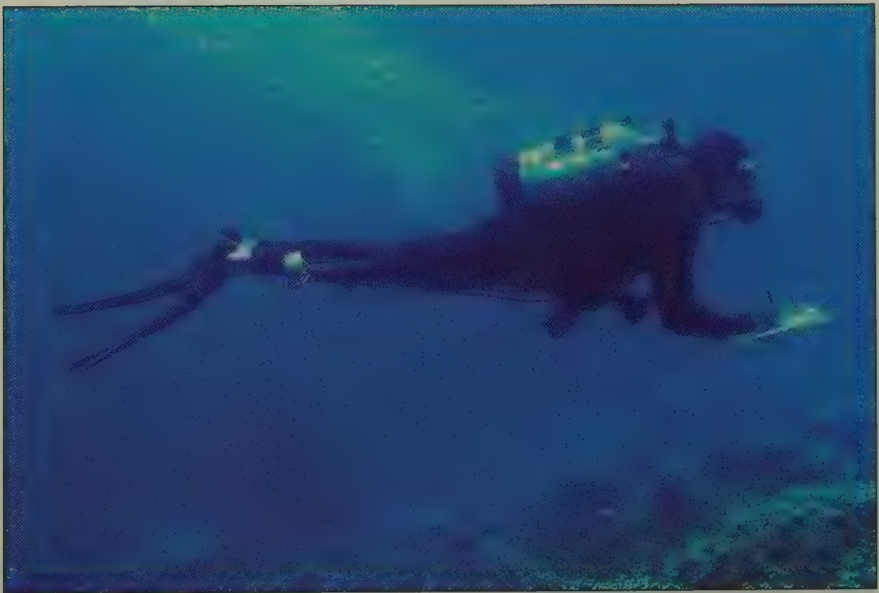


*Figure 8.50. "Jetboots" equipped diver conducting nearshore fish survey on the Kona coast of the Big Island. Photo: DLNR/DAR.*

had atypical amounts of physical relief (very high relief sites tending to have high adult yellow tang density, low relief sites having relatively low densities) or were adjacent to shallow sandy areas which lacked suitable adult yellow tang habitat (e.g., highest density of any site was a boundary site close to a large inshore sandy area unsuitable for adult yellow tangs). The three sites with lowest adult densities were furthest from a protected area (Figure 8.51).

These results provide strong evidence that adult stocks are now higher within reserves and in areas close to reserve boundaries than in areas which receive no benefit from adjacent reserves. Given that yellow tang are long-lived fishes, with a maximum lifespan of >35 years (J. Claisse, pers. comm.), and closures have only been in effect for only seven years there is considerable scope for further increases in adult stocks over time. Numbers of fishers and total catch have increased dramatically since the reserves were established and, therefore, the West Hawaii reserve network is providing a crucial buffer against future overexploitation of this species. As long as the FRA network remains in place and there continues to be high compliance, healthy stocks of adult yellow tangs should be maintained over large portions of the West Hawaii coastline. Because of larval dispersal, those healthy adult stocks in reserves and boundary areas will ensure the continued supply of new juveniles to the fishery and therefore the sustainability of the fishery.

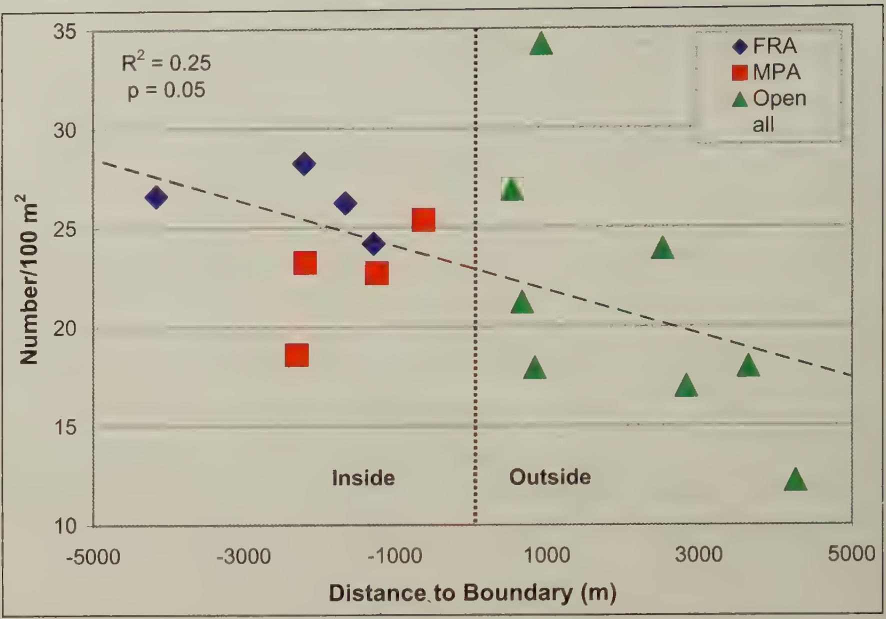


*Figure 8.51. Abundance of adult yellow tangs at jetboots survey sites inside and outside of West Hawaii marine protected areas (n=5). MPA refers to protected areas established in varying years prior to 2000. Aquarium collecting and some other types of fishing are prohibited in MPAs. FRA denotes Fish Replenishment Areas established at the beginning of 2000 which are closed only to aquarium collecting. Source: DLNR/DAR.*

## Local Action Strategies (LAS)

Hawaii used a collaborative planning process to develop six LAS to address key threats to coral reefs. The six key threat areas focused on initial LAS development were outreach and education, land-based sources of pollution, coral reef fisheries management, recreational impacts to reefs, aquatic invasive species, climate change and marine disease. This planning process supported and expanded on existing efforts already underway in the state. In cases where coordinating bodies did not already exist, steering committees were formed to facilitate the development and implementation of the particular LAS. These committees include members from state and federal government agencies, non-governmental organizations, academia, businesses and community groups. The committees: 1) assessed ongoing activities and the effectiveness of current management strategies; and 2) held a series of stakeholder workshops to discuss the issues, gaps and needs for addressing focus issues. Each LAS varied in the extent to which new initiatives were developed or existing efforts were supported or enhanced. Each LAS was developed using an extensive stakeholder input process.

### *Local Action Strategy to Address Land-based Pollution Threats to Coral Reefs*

Hawaii's Local Action Strategy to Address Land-based Pollution Threats to Coral Reefs is watershed-based. The LAS was developed to incorporate the holistic management aspects of traditional Hawaiian land and natural resource management at the watershed or "ahupuaa" level. The LAS partners with community stakeholders to focus on demonstration projects in three ahupuaa in the main Hawaiian Islands: Honolua, Maui; Kawela to Kapualei, Molokai; and Hanalei, Kauai. The overall goal of the LAS is to improve coastal water quality and coral ecosystem function and health by reducing land-based pollution. This is being achieved through the implementation of projects that: 1) Reduce pollutant load to surface water and groundwater through site-specific actions and best management practices; 2) Improve understanding of the links between land-based pollution and coral reef health through focused scientific research and monitoring; and 3) Increase awareness of pollution prevention and control measures statewide. The LAS has had several small successful projects implemented over the past three years and is now being revised to incorporate new information and to consider additional watersheds where community involvement is strong.

### *Aquatic Invasive Species Local Action Strategy (AIS-LAS)*

The purpose of the Hawaii's *AIS-LAS* is to act as a tool in which to help enhance the coordination of current management efforts, identify remaining problems areas and gaps, and recommend additional actions which are needed to effectively address AIS issues in Hawaii that affect coral reefs. The focus of the AIS LAS is the identification of feasible, cost-effective management practices to be implemented by state, federal, county, nongovernmental, private, and volunteer entities for the environmentally sound prevention and control of aquatic invasive species in a coordinated fashion. It is based on the comprehensive AIS Management Plan that was written in 2002 to bring together all stakeholders to address both marine and freshwater aquatic invasive species. Funding comes from several sources to undertake activities such as the "Habitattitude" campaign – a program to educate the public about the problems that released aquarium pets and plants can cause, as well as research and technology grants studying toxic dinoflagellates in ballast water.

*Recreational Impacts to Reefs Local Action Strategy (RIR-LAS)*
Hawaii's Local Action Strategy to address recreational impacts to reefs focuses on minimizing the impacts of recreational activities that have the potential to directly and indirectly impact reef ecosystem health such as breakage from physical contact, alterations in marine life behavior and degradation of surrounding water quality. The goal of the RIR-LAS is: "to determine the impacts of marine recreation activities on Hawaii's coral reef ecosystems and develop innovative management techniques that increase the environmental sustainability of those activities." Under the overarching goal, projects are organized into three objectives including: data, management and outreach. Currently the priorities are focusing on installation and use of day-use mooring buoys, human use assessment tool development and social carrying capacity research, tour operator stewardship training, supporting community stewardship efforts in high use coastal sites and developing outreach materials for distribution to users at point of rental orientation.

*Coral Reef Fisheries Local Action Strategy*
Hawaii's coral reef fisheries local action strategy has focused efforts on supporting community-based management activities at selected sites, understanding the life history characteristics of key reef fish species, determining the predator/prey relationships of introduced snappers and groupers to native reef fishes and providing support for enforcement. This LAS is also being revised to focus on a few key management needs.

*Climate Change and Marine Disease Local Action Strategy*
This is Hawaii's newest local action strategy, which was completed in late 2005. Preliminary efforts are focused on developing training materials for managers on coral disease and developing a rapid response protocol for bleaching and disease events.

*Hawaii Invasive Species Council (HISC)*
The state of Hawaii continues to address aquatic invasive species issues through a variety of means. HISC was created by the state legislature and appointed by the Governor to address both terrestrial and aquatic invasive species issues. HISC continues to fund the Aquatic Invasive Species Response Team at DAR, which has recently begun a program of hull inspections for all vessels traveling to the NWHI Monument to prevent or reduce the introduction of AIS from the Main Hawaiian Islands to the Monument. In addition, HISC has provided funding which address public outreach on targeted aquatic invasive species. HISC and other funders also supported the development of a Supersucker Jr. a more mobile version of the Supersucker discussed under threats. HISC and the DLNR/DAR also worked with the Hawaii Superferry (a new inter-island transportation option that started service in 2007) on planning ways to minimize the risk of inter-island spread of AIS.

*Recent Regulations*
Governor Lingle approved amendments to regulations restricting the use of lay nets and prohibiting their use in certain waters in the spring of 2006. Included are requirements for lay net registration, limits on dimensions and soak times, requirements for attendance and inspection, and prohibitions on use in streams and stream mouths. Lay net use is also prohibited around the entire island of Maui, and in certain waters off Oahu, including Kaneohe and Kailua Bays, and along three miles of the south shore between Koko Head and Pearl Harbor. Also in 2006, new laws and regulations were enacted which establish an "Ewa limu (seaweed) management area", where taking of plants is prohibited, as well as another that prohibits the taking or killing of female spiny lobsters, Kona crabs and Samoan crabs.

Community-Based Management Initiatives
The level of community stewardship involvement in marine resource management has increased markedly in the past few years. More and more communities are creating community groups to assist in caring for, monitoring and protecting high use sites throughout the state. In some sites this community planning and active participation in management is in response to growing concerns about levels of use, in others it is in response to perceived changes to lifestyle. There is currently a network of over 28 communities that meets twice a year to discuss concerns and compare notes on what they are each doing to care for the reef resources in their backyard. DAR worked with the Community Conservation Network to develop Caring for Coastal and Marine Communities: A Guidebook for Community Stewardship, to provide communities with the tools and a set of standard methods that could be employed to co-manage these resources.

## OVERALL CONCLUSIONS AND RECOMMENDATIONS

Food, recreation, culture, commerce, aesthetics, and shoreline protection are just a few of the ecosystem services provided by Hawaii's coral reefs. These reefs also have extremely high biodiversity and conservation value due to large proportion of species found nowhere else on earth. Hawaii's coral reefs, which have been valued at over U.S. $10 billion, are an important component of the economy and form the backbone for many of our leisure pursuits and way of life. However, the 1.2 million residents (over 70% of which live on Oahu) and over seven million tourists each year have put increasing pressure on Hawaii's coral reefs. A number of urban areas and popular tourist destinations have suffered from land-based sources of pollution, significant fishing pressure, recreational overuse, and alien species. Despite these anthropogenic stressors, many of Hawaii's coral reefs, particularly in remote areas, are still in fair to good condition.

The effects of fishing are evident at the level of individual stocks, as well as throughout the entire ecosystem. Enforcement remains a challenge statewide. Compliance with existing regulations is lacking and further complicated by minimal prosecution of natural resource violations which are not considered serious offences by the judiciary. Information on basic life-history parameters exists for few species and, current regulations fail to protect many species from harvest before first reproduction, much less consider the implications of sex changing species or the importance of larger and older individuals to total reproductive output. The non-commercial catch is enormous and a much greater emphasis needs to be placed on assessing these fisheries and how best to manage them. The integration of mapping and monitoring of coral reef ecosystems and reef fish habitat utilization patterns has assisted managers in making informed decisions about MPA design and effectiveness, as well as helping to define essential fish habitat and ecosystem function for ecosystem-based fisheries management decision making. The effects of intensive fishing pressure must be mitigated and stocks and ecosystems rebuilt through a series of coordinated measures including: additional restrictions on overly efficient gear types such as gillnets and SCUBA fishing (particularly at night), bag limits, and larger area closures.

Water quality in the MHI is generally very good and the majority of the coastal waters and upland surface waters are in good condition. However, in past years storm water runoff during high rain events into urban streams has caused a significant number of beach closures for human health and safety reasons. Nutrient inputs from sewage systems in need of upgrades into selected systems is of highest concern on the heavily developed and urbanized coasts of Oahu and Maui. Hawaii's groundwater quality is considered excellent overall and chemical contaminant concentrations detected in public groundwater/drinking water sources are normally below state and federal drinking water standards. Coastal waters (including nearshore coral reefs) that are impaired by pollutants are primarily harbors, semi-enclosed bays, and protected shorelines, where mixing is reduced and resident time of pollutants is long compared to exposed coasts. The most widely distributed coastal pollutants are nutrients, sediments and *Enterococcus*. However sediment discharge is probably the leading land-based pollutant causing alteration of reef community structure in the MHI. As coastal development continues to expand in the MHI, focus should be given to the implementation, maintenance, and enforcement of best management practices that reduce sediment runoff and prevent further damage to coral reefs. Holistic management approaches that consider the entire watershed from ridge to reef should also be encouraged and adopted wherever possible.

The continued invasion and degradation of new habitats by alien algae remains one of the most pressing threats to reefs in Hawaii. Preliminary research indicates that the suite of control methods developed by the HIMAG group can be an effective means of restoring affected reef habitats, but full-scale and full-time implementation of these methods (e.g., the Super Suckers) has not yet been achieved. Better information on the current distribution of alien algal species and the habitat requirements of these species is necessary to develop a comprehensive, state-wide management plan for addressing this threat. It is also clear that more investment in prevention activities must also be a priority. The fact remains the most cost effective method for managing invasive species is to prevent invasions.

One of the biggest obstacles to effective management is the lack of data on the status and trends of many important resources and ecosystem components. In addition, the scientific information available is not effectively translated to the public and policy makers. Due to its large research community, Hawaii is well poised to lead the way in effective management of insular coral reef ecosystems but currently lacks a coordinated focus. A comprehensive large-scale research initiative that includes state, federal, academic, non-profits, NGOs, and others partners would integrate existing research and management into a more holistic ecosystem-based approach that would greatly benefit Hawaii and serve as a model for other locations. A step towards this goal is the Hawaiian Archipelago Marine Ecosystem Research Plan, which strives to understand the entire archipelago's marine physical and biological environments, their dynamics and their interactions with human beings as a single connected system leading toward improved resource management. This ten year, multi-agency, collaborative program is proposed to advance ecosystem science and resource management in Hawaii through a better understand of the ecological function and natural states of resistance and resilience and compare these to the anthropogenic impacts experienced in the MHI.

A better knowledge of the spatial dynamics of Hawaii's reefs and the impacts to it are needed. GIS efforts to map existing data, identify gaps and develop predictive models require a greater level of support than currently exits. These tools need to also be provided to the managers through capacity building, training and funding for basic hardware and software. With adequate funding, these tools can then be used to identify where anthropogenic impacts are most likely to occur as well as determine sites of high biodiversity potential that are not currently protected and determine means to protect these sites. This broad-scale seascape approach will also provide information relevant to predictive species mapping and marine reserve design.

Community-based management has been effective in a number of locations in Hawaii and the expansion of these efforts will ensure that key socioeconomic and cultural concerns are well integrated in research and management. Programs like Makai Watch provide local communities the opportunity to become directly involved in the protection of their local coastal resources and should be expanded and integrated into the management decision-making process. A better understanding of the socio/cultural and biological importance of a site is critical to effective assessment of management strategies. Locally-managed marine areas that incorporate traditional concepts of customary marine tenure have been effective in many Pacific Islands. Including elements of these established and recognized practices into a contemporary framework will increase the legitimacy of management decisions and makes compliance with rules and regulations easier.

Hopefully, conserving entire ecosystems and variety of all habitats will be the focus of management in the coming years. A more holistic approach to place-based management will require comprehensive ocean zoning if we are to resolve the mismatches between spatial and temporal scales of governance and ecosystems. To achieve ecosystem-based management, a spatially explicit approach will be required to better understanding the patterns and processes that regulate ecosystem function and to ensure the sustainability and benefits of the entire ecosystem to society.

## REFERENCES

Aeby, G.S. 2006. Baseline levels of coral disease in the Northwestern Hawaiian Islands. Atoll Res. Bull. 543: 471-488.

Aeby G.S., J.C. Kenyon, J.E. Maragos, and D.C. Potts. 2003. First record of mass coral bleaching in the northwestern Hawaiian Islands. Coral Reefs 22: 256.

Ambrose, E., K. Takahashi, D. Regan, K. Crozier, B. Akiona, A. Lee, W. Dudley, and S. Maynard. 1988. Nearshore baseline survey of Olowalu Maui, Hawaii. Marine Operations Program, University of Hawaii at Manoa. Honolulu, HI. 120 pp.

Anderson, B.D. 1978. Coral community structure at Hanauma Bay, Oahu, Hawaii: a model for coral reef management. Ph.D. Thesis. Heed University. 150 pp.

Anthony, S.S., C.D. Hunt, A.M.D. Brasher, L.D. Miller, and M.S. Tomlinson. 2004. Water quality on the Island of Oahu, Hawaii, 1999-2001. U.S. Geological Survey Circular 1239. Reston, VA. 37 pp.

Balazs, G.H. and S.G. Pooley. 1991. Research Plan for marine turtle fibropapilloma. NOAA Technical Memorandum NMFS SWFSC 156. Honolulu, HI. 113 pp.

Brown, E.K. 2004. Reef coral populations: Spatial and temporal differences observed at six reefs off West Maui. Ph.D. Thesis, University of Hawaii at Manoa. Honolulu, HI. 277 pp.

Brown, E.K., E.F. Cox, B. Tissot, P.L. Jokiel, K.S. Rodgers, W.R. Smith, and S.L. Coles. 2004. Development of benthic sampling methods for the Coral Reef Assessment and Monitoring Program (CRAMP) in Hawaii. Pac. Sci. 58(2): 145-158.

Cesar, H.S.J. and P.J.H. van Beukering. 2004. Economic valuation of the coral reefs of Hawaii. Pac. Sci. 58(2): 231-242.

Claisse, J. Hawaii Cooperative Fishery Research Unit, Department of Zoology, University of Hawaii at Manoa. Honolulu, Hawaii. Personal communication.

Coles, S.L. 1998. Annual report- Kahe generating station NPDES monitoring report for 1997. Hawaiian Electric Co., Inc. Honolulu, HI.

Coles, S.L. and B.E. Brown. 2003. Coral bleaching - Capacity for acclimatization and adaptation. Adv. Mar. Biol. 46: 183-223.

Coles, S.L. and E. Brown. 2007. Twenty-five years of change in coral coverage on a hurricane impacted reef in Hawaii: The importance of recruitment. Coral Reefs 26: 705-717.

Coles, S.L., J. Marchetti, H. Bolick, and A. Montgomery. 2007. Assessment of invasiveness of the Orange Keyhole Sponge *Mycale armata* in Kaneohe Bay, Oahu, Hawaii. Final year 2 report to the Hawaii Coral Reef Initiative Program. Contribution No. 2007–002 to the Hawaii Biological Survey. Honolulu, HI.

Coyne, M.S., M.E. Monaco, T.A. Battista, M. Anderson, J. Waddell, W. Smith, P. Jokiel, and M.S. Kendall. 2003. Benthic habitats of the main Hawaiian Islands. NOAA Technical Memorandum NOS NCCOS 152. Silver Spring, MD. 103 pp. http://ccmaserver.nos.noaa.gov/products/biogeography/hawaii_cd/startup.htm.

DeMartini, E.E. and A.M. Friedlander. 2004. Spatial patterns of endemism in shallow water reef fish populations of the Northwestern Hawaiian Island. Mar. Ecol. Prog. Ser. 271: 281-296.

DeFelice, R.C. and J.D. Parrish. 2003. Importance of benthic prey for fishes in coral reef-associated sediments. Pac. Sci. 57(4): 359-384.

Dollar, S.J. 1982. Wave stress and coral community structure in Hawaii. Coral Reefs 1: 71-81.

Dollar, S.J. and G.W. Tribble. 1993. Recurrent storm damage and recovery: a long-term study of coral communities in Hawaii. Coral Reefs 12: 223-233.

Dollar, S.J. and R.W. Grigg. 2004. Anthropogenic and natural stresses on selected coral reefs in Hawaii: A multidecade synthesis of impact and recovery. Pac. Sci. 58(2): 281-304.

Domart-Coulon, J., N. Traylor-Knowles, E. Peters, D. Elbert, C. Downs, K. Price, J. Stubbs, S. McLaughlin, E. Cox, G. Aeby, P. Brown and G. Ostrander. 2006. Comprehensive characterization of skeletal tissue growth anomalies of the finger coral *Porites compressa*. Coral Reefs 25: 531-543.

Environmental Consultants, Inc. 1974. Honolua Bay Study: Geological, Physical, and Biological Surveys. Prepared for Belt, Collins and Associates. Report ECI-06. 62 pp.

Everson, A. and A.M. Friedlander. 2004. Catch, effort, and yields for coral reef fisheries in Kaneohe Bay, Oahu and Hanalei Bay, Kauai: comparisons between a large urban and a small rural embayment. pp. 110-31. In: A.M. Friedlander (ed.). Status of Hawaii's coastal fisheries in the new millennium. Proceedings of a symposium sponsored by the American Fisheries Society, Hawaii Chapter. Honolulu, HI.

Fenner, D. 2005. Corals of Hawaii. Mutual Publishing. Honolulu, HI. 143 pp.

Flament, P., S. Kennan, R. Lumpkin, M. Sawyer, and E.D. Stroup. 1996. The Ocean Atlas of Hawaii. Department of Oceanography, School of Ocean and Earth Science and Technology, University of Hawaii at Manoa. http://radlab.soest.hawaii.edu/atlas/.

Font, W.F. and M.C. Rigby. 2000. Implications of a new Hawaiian host record from blue-lined snappers *Lutjanus kasmira*: is the nematode *Spirocamallanus istiblenni* native or introduced? Bishop Mus. Occ. Pap. 64: 53-56.

Friedlander, A.M. (ed.). 2004. Status of Hawaii's coastal fisheries in the new millennium. Proceedings of a symposium sponsored by the American Fisheries Society, Hawaii Chapter. Honolulu, HI.

Friedlander, A.M., R.C. DeFelice, J.D. Parrish, and J.L. Frederick. 1997. Habitat resources and recreational fish populations at Hanalei Bay, Kauai. Hawaii Cooperative Fishery Research Unit, Department of Zoology, University of Hawaii at Manoa. Honolulu, HI. 320 pp.

Friedlander, A.M. and J.D. Parrish. 1997. Fisheries harvest and standing stock in a Hawaiian Bay. Fish. Res. 32(1): 33-50.

Friedlander, A.M. and J.D. Parrish. 1998a. Temporal dynamics of the fish assemblage on an exposed shoreline in Hawaii. Environ. Biol. Fish. 53:1-18.

Friedlander, A.M. and J.D. Parrish. 1998b. Habitat characteristics affecting fish assemblages on a Hawaiian coral reef. J. Exp. Mar. Biol. Ecol. 224(1): 1-30.

Friedlander, A.M., J.D. Parrish, and R.C. DeFelice. 2002. Ecology of the introduced snapper *Lutjanus kasmira* (Forsskal) in the reef fish assemblage of a Hawaiian bay. J. Fish Biol. 60: 28-48

Friedlander, A.M., E.K. Brown, P.L. Jokiel, W.R. Smith, and K.S. Rodgers. 2003. Effects of habitat, wave exposure, and marine protected area status on coral reef fish assemblages in the Hawaiian archipelago. Coral Reefs 22: 291-305.

Friedlander, A.M. and E.K. Brown. 2006. Hanalei benthic communities since 1992: spatial and temporal tends in a dynamic Hawaiian coral reef ecosystem. Hawaii Cooperative Studies Unit Technical Report HCSU-003. Hawaii Cooperative Studies Unit, Pacific Aquaculture and Coastal Resources Center, University of Hawaii at Hilo. Hilo, HI. 44 pp.

Friedlander, A.M., E.K. Brown, M.E. Monaco, and A. Clark. 2006. Fish Habitat Utilization Patterns and Evaluation of the Efficacy of Marine Protected Areas in Hawaii: Integration of NOAA Digital Benthic Habitat Mapping and Coral Reef Ecological Studies. NOAA Technical Memorandum NOS NCCOS 23. Silver Spring, MD. 217 pp. http://ccma.nos.noaa.gov/ecosystems/coralreef/hi_rfh.html.

Friedlander, A.M., E.K. Brown, and M.E. Monaco. 2007a. Coupling ecology and GIS to evaluate efficacy of marine protected areas in Hawaii. Ecol. Appl. 17: 715-730.

Friedlander, A.M., E.K. Brown, and M.E. Monaco. 2007b. Defining Reef Fish Habitat Utilization Patterns in Hawaii: Comparisons Between Marine Protected Areas and Areas Open to Fishing. Mar. Ecol. Prog. Ser. 351: 221-233.

Friedlander, A.M. and E.K. Brown. In review. Resistance and resilience of a Hawaiian coral reef ecosystem to dynamic natural conditions. Coral Reefs.

Grigg, R.W. 1965. Ecology of black coral in Hawaii. M.S. thesis, University of Hawaii at Manoa. Honolulu, HI.

Grigg, R.W. 1976. Fishery management of precious and stony corals in Hawaii. Sea Grant Technical Report, UNIHI-SEAGRANT-TR77-03. University of Hawaii. Honolulu, HI. 48 pp.

Grigg, R.W. 2001. Status of the black coral fishery in Hawaii, 1998. Pac. Sci. 55: 291-299.

Grigg, R.W. 2004. Harvesting impacts and invasion by an alien species, Carijoa riisei. Coral Reefs 22: 121-122.

Hamnett, M., M. Lui, and D. Johnson. 2006. Fishing, ocean recreation, and threats to Hawaii's coral reefs. Social Science Research Institute, University of Hawaii at Manoa. Honolulu, HI. 6 pp.

Hawaii DBEDT (Department of Business, Economic Development and Tourism). 2005. State of Hawaii Data Book: A statistical abstract. Honolulu, HI. 58 pp.

Hawaii State Department of Health (HIDOH). 2006. Beaches Environmental Assessment and Coastal Health Act 2006 Notification Report to the U.S. Environmental Protection Agency. Clean Water Branch, State of Hawaii Department of Health. Honolulu, HI.

Hawaii State Department of Health (HIDOH). 2008. 2006 State of Hawaii water quality monitoring and assessment report: Integrated report to the U.S. Environmental Protection Agency and the U.S. Congress Pursuant to Sections 303(D) and 305(B), Clean Water Act (P.L. 97-117). Water Quality Management Program, Hawaii State Department of Health. Honolulu, HI. 279 pp. http://hawaii.gov/health/environmental/env-planning/wqm/wqm.html%20#2006report.

Hayes, T.A., T.F. Hourigan, S.C. Jazwinski, J.D. Johnson Sr., and D.J. Walsh. 1982. The coastal resources, fisheries and fishery ecology of Puako, West Hawaii. Cooperative Fishery Research Unit, University of Hawaii. Honolulu, HI. Technical Report 82-1. 159 pp.

Hoegh-Guldberg, O. 1999. Climate change, coral bleaching and the future of the world's coral reefs. Mar. Freshw. Res. 50(8): 839-866.

Hunt Jr., C.D. 2007. Ground-Water Nutrient Flux to Coastal Waters and Numerical Simulation of Wastewater Injection at Kihei, Maui, Hawaii. U.S. Geological Survey Scientific Investigations Report 2006-5283. 69 pp. http://pubs.usgs.gov/sir/2006/5283/.

Hunter, C.L. and C.W. Evans. 1995. Coral reefs in Kaneohe Bay, Hawaii: Two centuries of western influence and two decades of data. Bull. Mar. Sci. 57(2): 501-515.

Hunter, C.L., M.D. Stephenson, R.S. Tjeerdema, D.G. Crosby, G.S. Ichikawa, J.D. Goetzl, K.S. Paulson, D.B. Crane, M. Martin, and J.W. Newman. 1995. Contaminants in oysters in Kaneohe Bay. Mar. Poll. Bull. 30: 646-654.

Hunter, C.L. 1999. Ecological Success of Alien Invasive Algae in Hawaii. Hawaii Coral Reef Initiative. Honolulu, HI. 48 pp. http://www.botany.hawaii.edu/GradStud/smith/websites/alien-overview.htm.

Intergovernmental Panel on Climate Change (IPCC). Climate Change 2007: The Physical Science Basis, Summary for Policy Makers, Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Geneva, Switzerland. 21 pp.

Jokiel, P.T. 1987. Ecology, biogeography and evolution of corals in Hawaii. TREE 2(7): 179-182.

Jokiel, P.L. and S.L. Coles. 1990. Response of Hawaiian and other Indo-Pacific reef corals to elevated temperatures associated with global warming. Coral Reefs 8: 155-162.

Jokiel, P.L. and E.K. Brown. 2004. Global warming, regional trends and inshore environmental conditions influence coral bleaching in Hawaii. Global Change Biol. 10: 1627-1641.

Jokiel, P.L., E.K. Brown, A.M. Friedlander, S.K. Rodger, and W.R. Smith. 2004. Hawaii coral reef assessment and monitoring program: Spatial patterns and temporal dynamics in reef coral communities. Pac. Sci. 58(2): 159-174.

Kahng, S.E. and J.E. Maragos. 2006. The deepest zooxanthellate, scleractinian corals in the world? Coral Reefs 25(2): 254.

Kamakau, S.M. 1839. Na Hana a ka Poe Kahiko The Works of the People of Old Translated by M.K. Pukui, Bernice P. Bishop Museum, Special Publication No. 61. (1976 ed.). Bishop Museum Press. Honolulu, HI. 170 pp.

Kay, E.A. and S.R. Palumbi. 1987. Endemism and evolution in Hawaiian marine invertebrates. TREE 2(7): 183-186.

Kenyon, J. and R. Brainard. 2006. Second recorded episode of mass coral bleaching in the Northwestern Hawaiian Islands. Atoll Res. Bull. 543: 505-523.

Kenyon, J.G., R. Aeby, J. Brainard, M. Chojnacki, C. Dunlap, and C. Wilkinson. 2006a. Mass coral bleaching on high-latitude reefs in the Hawaiian Archipelago. pp. 631-643. In: In: Y. Suzuki, T. Nakamori, M. Hidaka, H. Kayanne, B.E. Casareto, K. Nadaoka, H. Yamano, and M. Tsuchiya (eds.). Proceedings of the 10th International Coral Reef Symposium. Okinawa, Japan. 1950 pp.

Kenyon, J.C., P.S. Vroom, K.N. Page, M.D. Dunlap, C.B. Wilkinson, and G.S. Aeby. 2006b. Community structure of hermatypic corals at French Frigate Shoals in the Northwestern Hawaiian Islands: capacity for resistance and resilience to selective stressors. Pac. Sci. 60(2): 151-173.

Kenyon JC and Aeby GS. In review. Localized outbreak of the crown-of-thorns starfish *Acanthaster planci* (Echinodermata, Asteroidea) on reefs off Oahu, Hawaii. In review, Bulletin of Marine Science.

Kinzie, R.A. 1972. A survey of the shallow water biota of Maalaea Bay, Maui. Final Report: Westinghouse Electric Corp. Contract #C-138.

Kohler, E. and S.M. Gill. 2006. Coral Point Count with Excel extensions (CPCe): A Visual Basic program for the determination of coral and substrate coverage using random point count methodology. Comp. Geosci. 32: 1259-1269.

Maragos, J.E. 1972. A study of the ecology of Hawaiian reef corals. Ph.D. Thesis. University of Hawaii at Manoa. Honolulu, HI. 290 pp.

Maragos, J.E., D.C. Potts, G.S. Aeby, D. Gulko, J.C. Kenyon, D. Siciliano, and D. VanRavenswaay. 2004. 2000-2002 Rapid Ecological Assessments of corals (Anthozoa) on shallow reefs of the Northwestern Hawaiian Islands. Part 1: species and distribution. Pac. Sci. 58(2): 211-230.

Marsh, C. Maui Divers of Hawaii Ltd. Honolulu, HI. Personal communication.

MTP Inc. (Market Trends Pacific, Inc. and John Knox and Associates, Inc.). 2006. 2006 Survey of Resident Sentiments on Tourism in Hawaii: Analysis and Report. Prepared for Hawaii Tourism Authority. Honolulu, HI. 82 pp. http://www.hawaiitourismauthority.org/index.cfm?page=1rp_reports_archive.

Oda, D.K. and J.D. Parrish. 1982. Ecology of commercial snappers and groupers introduced to Hawaiian reefs. pp. 59-67. In: E.D. Gomez, C.E. Birkeland, R.W. Buddemeier, R.E. Johannes, J.A. Marsh Jr., and R.T. Tsuda (eds.). Proceedings of the 4th International Coral Reef Symposium, Vol. 1. Manila, Philippines. 720 pp.

Oishi, F. 1990. Black coral harvesting and marketing activities in Hawaii – 1990. Division of Aquatic Resources, Department of Land and Natural Resources, State of Hawaii. Honolulu, HI. 13 pp.

Okihiro, M.S. 1988. Chromatophoromas in two species of Hawaiian butterflyfish, *Chaetodon multicinctus* and *C. miliaris*. Vet. Pathol. 25: 422-431.

Orazio, C., T. May, and W.W.M. Steiner. 2003. U.S. Geological Society Final Reports CERC-8335-FY03-31-01 and CERC-8335-FY02-32-14. http://www.hanaleiwatershedhui.org/science/contaminants.htm.

Pyle, R. Bishop Museum. Honolulu, HI. Personal communication.

Quackenbush, S.L., T.M. Work, G.H. Balazs, R.N. Casey, J. Rovnak, A. Chaves, L. DuToit, J.D. Baines, C.R. Parrish, P.R. Bowser, and J.W. Casey. 1998. Three closely related herpesviruses are associated with fibropapillomatosis in marine turtles. Virology 246: 392-399.

Randall, J.E. 1987. Introduction of marine fishes to the Hawaiian Islands. Bull. Mar. Sci. 41: 490-502.

Randall, J.E. 1998. Zoogeography of shore fishes of the Indo-Pacific region. Zool. Stud. 37: 227–268.

Richmond, R.H. 1993. Coral reefs: present problems and future concerns resulting from anthropogenic disturbance. Am. Zool. 33: 524-536.

Rooney, J.J.B., C.H. Fletcher, E.E. Grossman, M. Engels, and M.E. Field. 2004. El Nino influence on Holocene reef accretion in Hawaii. Pac. Sci. 58(2): 305-324.

Rooney, J.J.B. and C. Fletcher. 2005. Shoreline Change and Pacific Climatic Oscillations in Kihei, Maui, Hawaii. J. Coast. Res. 21:535–547

Schumacher, B.D. and J.D. Parrish. 2005. Spatial relationships between an introduced snapper and native goatfishes on Hawaiian reefs. Biol. Invasions 7: 925-933.

Shomura, R. 1987. Hawaii's marine fishery resources: yesterday (1900) and today (1986). NOAA NMFS SWFSC Administrative Report H-87-21. 14 pp.

Shomura, R. 2004. A historical perspective of Hawaii's marine resources, fisheries, and management issues over the past 100 years. Honolulu, Hawaii. pp. 6-11. In: A.M. Friedlander (ed.). Status of Hawaii's coastal fisheries in the new millennium. Proceedings of a symposium sponsored by the American Fisheries Society, Hawaii Chapter. Honolulu, HI.

Sladek Nowles, J. and A. M. Friedlander. 2004. Research priorities and techniques. pp. 187-233. In: J. Sobel and C. Dahlgren (eds.). Marine Reserves; their science, design and use. Island Press. Washington, DC. 410 pp.

Sladek Nowlis, J., A.M. Friedlander, and E.E. DeMartini. In review. Dramatic ecological effects of fishing revealed using a new assemblage assessment tool that relies on a large unfished reference area. Conserv. Biol.

Smith, J.E., J.W. Runcie, and C.M. Smith. 2005. Characterization of a large-scale ephemeral bloom of the green alga *Cladophora sericea* on the coral reefs of West aui, Hawaii. Mar. Ecol. Prog. Ser. 302: 77-91.

Soicher, A.J. and F.L. Peterson. 1997. Terrestrial nutrient and sediment fluxes to the coastal waters of West Maui, Hawaii. Pac. Sci. 51(3): 221 - 232.

Storlazzi, C.D., M.E. Field, P.L. Jokiel, K.S. Rodgers, E. Brown, and J.D. Dykes. 2005. A model for wave control on coral breakage and species distribution in the Hawaiian Islands. Coral Reefs 24: 43-55.

The Ocean Conservancy. 2006. 2005 International Coastal Cleanup Hawaii Summary Report. http://www.oceanconservancy.org/site/News2?page=NewsArticle&id=8635.

Tissot, B.N., W. Walsh, J. Hallacher, and E. Leon. 2004. Evaluating Effectiveness of a Marine Protected Area Network in West Hawaii to Increase Productivity of an Aquarium Fishery. Pac. Sci. 58: 175-188.

Titcomb, M. 1972. Native use of fish in Hawaii. University of Hawaii Press. Honolulu, HI. 188 pp.

Torricer, L., G. Akita, G. A. Anzai, L. Boucher, R. Fantine, T. Kobayashi, G. Muraoka, H. Price, and S. Takenaka. 1979. Marine Option Program data acquisition project: Honolua Bay, Maui. Sea Grant College Program, University of Hawaii. Honolulu, HI. 38 pp.

USEPA (U.S. Environmental Protection Agency). 1998. Climate Change and Hawaii. EPA 236-F-98-007e. Climate and Policy Assessment Division. http://yosemite.epa.gov/oar/GlobalWarming.nsf/UniqueKeyLookup/SHSU5BUNQM/$File/hi_impct.pdf.

Vroom, P.S., K.N. Page, J.C. Kenyon, and R.E. Brainard. 2006. Algae-Dominated Reefs. Am. Sci. 94: 430-437.

Walsh, W.J., S.P. Cotton, J. Dierking and I.D. Williams. 2004. The commercial marine aquarium fishery in Hawaii 1976-2003. pp. 132-159. In: A.M. Friedlander (ed.). Status of Hawaii's Coastal Fisheries in the New Millennium. Proceedings of a Symposium sponsored by the American Fisheries Society, Hawaii Chapter. Honolulu, HI.

Work, T.M., R.A. Rameyer, G. Takata, and M.L. Kent. 2003. Protozoal and epitheliocystis-like infections in the introduced blueline snapper *Lutjanus kasmira* in Hawaii. Dis. Aquat. Org. 37: 59-66.

Yuen and Associates. 1992. State Water Resources Protection Plan: Vol. II. Commission on Water Resource Management, State of Hawaii. 214 pp.

Zeller, D., S. Booth, and D. Pauly. 2005. Reconstruction of coral reef-and bottom-fisheries catches for US flag island areas in the Western Pacific, 1950 to 2002. Western Pacific Regional Fishery Management Council. Honolulu, HI. 113 pp.

# The State of Coral Reef Ecosystems of the Northwestern Hawaiian Islands

Alan Friedlander[1,2], Greta Aeby[3], Seema Balwani[4], Brian Bowen[3], Russell Brainard[4], Athline Clark[5], Jean Kenyon[4,6], James Maragos[7], Carl Meyer[3], Peter Vroom[4,6] and Jill Zamzow[5,8]

Contributors: Ed DeMartini[9], Erik Franklin[3], Ruth Gates[3], Jamison Gove[4,6], Scott Godwin[3,10], Amy Hall[4,6], Paul Jokiel[3], Chris Kelley[11], Beth Flint[7], Rob Toonen[3], Kim Holland[12], Carey Morishige[13,14], Joyce Miller[4,6], Robert Moffitt[9], Russell Moffitt[9], Yannis Papastamatiou[3], Karen Rosa[7], Ellen Smith[4,6], Robert Schroeder[4,6], Michael Stat[3] and Bernardo Vargas-Angel[4,6]

## INTRODUCTION AND SETTING

Beginning at Nihoa and Necker Island (Mokumanamana; about 7 and 10 million years old, respectively) and extending to Midway and Kure Atolls (about 28 million years old), the NWHI represent the older portion of the emergent Hawaiian Archipelago (Grigg, 1988). The NWHI are set in a dynamic oceanographic and meteorological regime in the northern/central subtropical region of the Pacific Ocean (Figure 9.1). The boundary between the nutrient-poor surface waters of North Pacific Subtropical Gyre and the nutrient-rich surface waters of the North Pacific Subpolar Gyre frequently influence the NWHI region (Leonard et al., 2001; Polovina et al., 2001). This front shifts seasonally (Polovina et al., 2001) and migrates on interannual and decadal time scales, bringing colder and nutrient rich waters that are likely important to the productivity and ecology of the region.

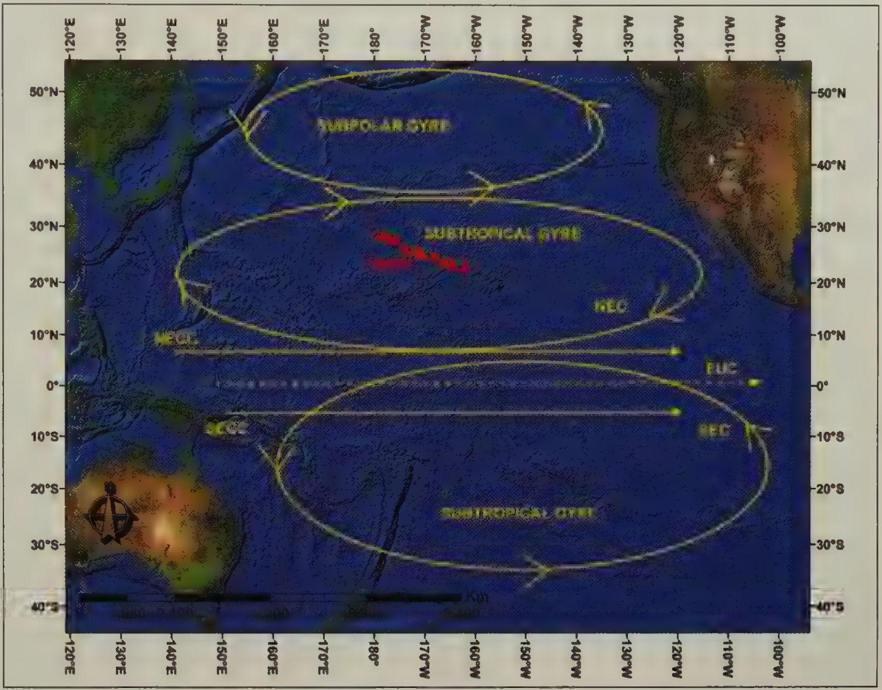


*Figure 9.1. Topographic map showing location in Pacific Ocean of the NWHI and the major ocean currents in the region: North Equatorial Current (NEC), South Equatorial Current (SEC), North Equatorial Counter Current (NECC), South Equatorial Counter Current (SECC), Equatorial Under Current (EUC). Source: Pacific Islands Fishery Science Center-Coral Reef Ecosystem Division (PIFSC-CRED).*

On June 15, 2006, President George W. Bush designated the Northwestern Hawaiian Islands (NWHI) as a Marine National Monument, one of the largest conservation areas on earth, through the signing of Presidential Proclamation 8031. The Monument encompasses nearly 362,600 $km^2$ (140,000 $mi^2$) of ocean and includes all the islands, atolls, shoals and banks from Nihoa Island to Kure Atoll (Figure 9.2). In March 2007, First Lady Laura Bush renamed the Monument the Papahanaumokuakea Marine National Monument (PMNM) on behalf of the President.

One of the most striking and unique components of the NWHI ecosystem is the abundance and dominance of large apex predators such as sharks and jacks (Friedlander and DeMartini, 2002), which exert a strong top-down control on the ecosystem (DeMartini et al., 2005; DeMartini and Friedlander, 2006) and have been depleted in most other locations around the world (Meyer and Worm, 2003, 2005). The geographic isolation of the Hawaiian Islands has resulted in some of the highest endemism of any tropical marine ecosystem on earth (Kay and Palumbi, 1987; Jokiel, 1987; Randall, 2007). Some of these endemic species are a dominant component of the community, resulting in a unique ecosystem that has extremely high conservation value and identifies Hawaii as an important global biodiversity hotspot (DeMartini and Friedlander, 2004; Maragos et al., 2004; Roberts et al., 2002; Allen, 2002). The few alien species known from the NWHI are restricted to islands with anthropogenic impacts such as Midway Atoll and French Frigate Shoals (Friedlander et al., 2005; Godwin et al., 2006). Disease levels in corals in the NWHI are much lower than those reported from other locations in the Indo-Pacific (Aeby, 2006).

---

1. NOAA/ NOS/ NCCOS/ Center for Coastal Monitoring and Assessment, Biogeography Branch
2. The Oceanic Institute
3. University of Hawaii, Hawaii Institute of Marine Biology
4. NOAA/ NMFS/ Pacific Islands Fishery Science Center, Coral Reef Ecosystem Division
5. Hawaii Department of Land and Natural Resources, Division of Aquatic Resources
6. Joint Institute for Marine and Atmospheric Research
7. U.S. Fish and Wildlife Service
8. NOAA/ NOS/ NMSP/ Papahanaumokuakea Marine National Monument
9. NOAA/ NMFS/ Pacific Islands Fishery Science Center
10. Bishop Museum
11. Hawaii Undersea Research Laboratory
12. University of Hawaii, Department of Zoology
13. NOAA Marine Debris Program
14. Hawaii Sea Grant

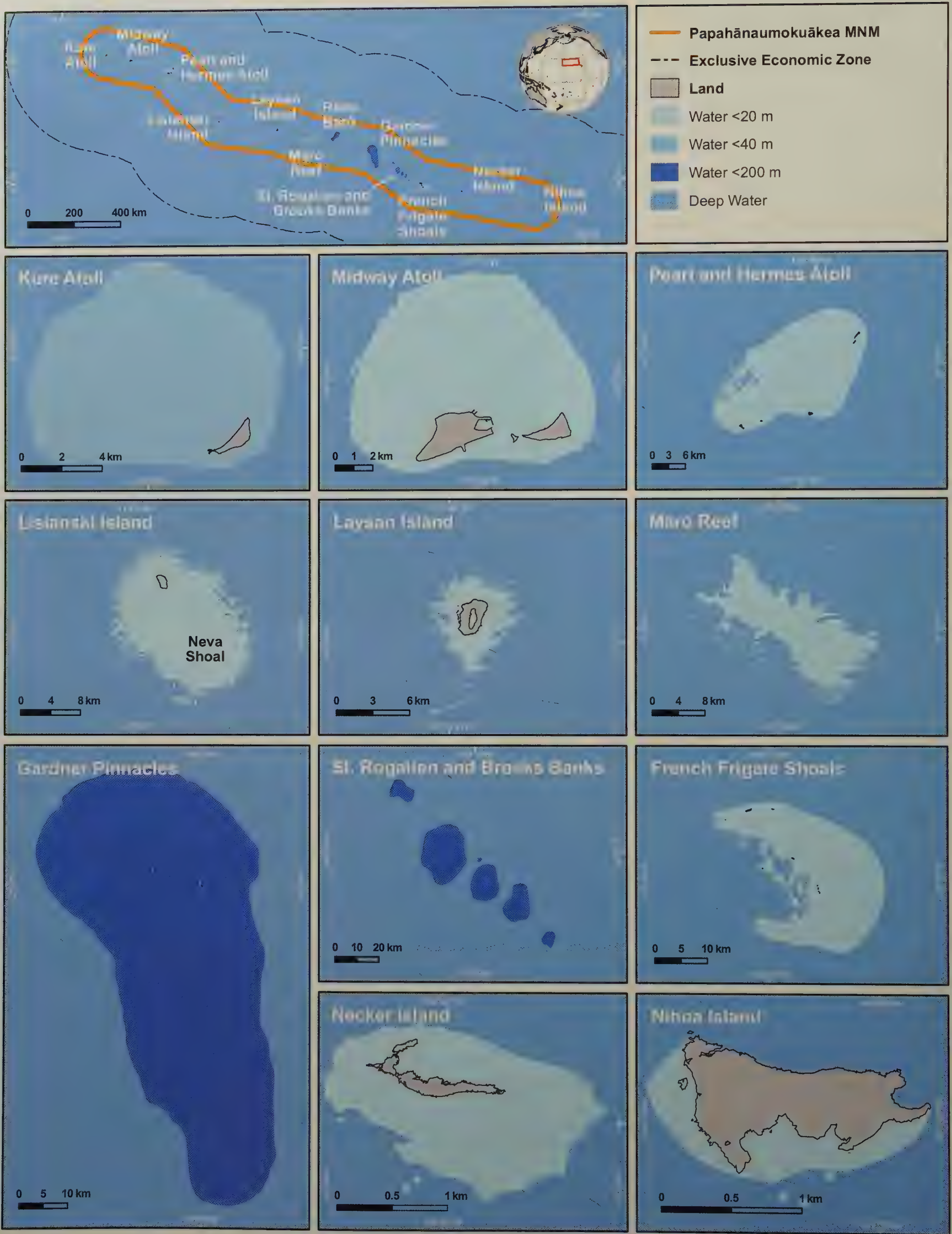

Kure Atoll
Midway Atoll
Pearl and Hermes Atoll
Lisianski Island
Laysan Island
Raita Bank
Gardner Pinnacles
Maro Reef
St. Rogatien and Brooks Banks
French Frigate Shoals
Necker Island
Nihoa Island
0 200 400 km
Papahānaumokuākea MNM
Exclusive Economic Zone
Land
Water <20 m
Water <40 m
Water <200 m
Deep Water
Kure Atoll
0 2 4 km
Midway Atoll
0 1 2 km
Pearl and Hermes Atoll
0 3 6 km
Lisianski Island
Neva Shoal
0 4 8 km
Laysan Island
0 3 6 km
Maro Reef
0 4 8 km
Gardner Pinnacles
0 5 10 km
St. Rogatien and Brooks Banks
0 10 20 km
French Frigate Shoals
0 5 10 km
Necker Island
0 0.5 1 km
Nihoa Island
0 0.5 1 km

*Figure 9.2. Locator map of the Northwestern Hawaiian Islands.* ***NOTE:*** *Island abbreviations in figures and tables are as follows: Kure Atoll=KUR; Midway Atoll=MID; Pearl and Hermes Atoll=PHR; Lisianski Island=LIS; Laysan Island=LAY; Maro Reef=MAR; French Frigate Shoals=FFS; Gardner Pinnacles=GAR; Necker Island=NEC; Nihoa Island=NIH and RAI=Raita Bank. Map: K. Buja.*

The NWHI represent important habitat for a number of threatened and endangered species. The Hawaiian monk seal (*Monachus schauinslandi*) is one of the most critically endangered marine mammals in the U.S. (about 1,200 individuals) and depends almost entirely on the islands of the NWHI for breeding and the surrounding reefs for sustenance (Antonelis et al., 2006). Over 90% of all sub-adult and adult Hawaiian green sea turtles (*Chelonia mydas*) found throughout Hawaii inhabit the NWHI (Balazs et al., 2006). Additionally, seabird colonies in the NWHI constitute one of the largest and most important assemblages of seabirds in the world (USFWS, 2005). The remoteness and limited fishing and other human activities that have occurred in the NWHI have resulted in minimal anthropogenic impacts (Friedlander et al., 2005), therefore providing a unique opportunity to assess how a "natural" coral reef ecosystem functions in the absence of major localized human intervention and contrast these findings with the main Hawaiian Islands (MHI) and other ecosystems that experience high levels of anthropogenic influence (Grigg et al., in press).

## ENVIRONMENTAL AND ANTHROPOGENIC STRESSORS

### Climate Change and Coral Bleaching

Mass coral bleaching affected numerous shallow reefs throughout the NWHI in 2002 and 2004 (Figure 9.3). In both years, the incidence of bleaching was greater at the three northern atolls (Kure, Pearl and Hermes, Midway) than at Lisianski and locations further south. At the three northern atolls, bleaching was most severe in shallow back reef and lagoon habitats. In both years, colonies in the genera *Montipora* and *Pocillopora* sustained the highest levels of bleaching (Kenyon et al., 2006a; Kenyon and Brainard, 2006). Prolonged periods of elevated sea surface temperatures (SST) coinciding with anomalously light wind speeds are thought to be the cause (Figure 9.4; Hoeke et al., 2006). In comparison, only low levels of bleaching were observed during 2006 surveys (Figure 9.5), which were conducted at the same time of year (September) as those in 2002 and 2004. Colonies in the genus *Montipora* were again most affected by bleaching in 2006.

In 2004, visual estimates of mortality and algal overgrowth of *Montipora capitata* and *M. turgescens* at back reef sites at the three northern atolls conservatively exceeded 50%, with nearly complete mortality of surface-facing portions of colonies at numerous sites. The shallow crest of a large central patch reef system at Kure Atoll, known previous to 2002 as "the coral gardens" due to its luxuriant growth of corals, was heavily bleached in 2002. In 2004 only a few branches of *Porites compressa* remained alive, and the dead coral skeletons were thickly covered in turf and macroalgae. Little change was observed in this reef's condition during 2006 surveys. A striking shift occurred at this location from a system dominated by coral in 2001 to a system dominated by algae in 2004 (Figure 9.6).

The increase in water temperatures associated with global warming (1-2°C per century) and the regionally specific El Niño-Southern Oscillation (ENSO) events are causing a breakdown in the coral-algal symbiotic re-

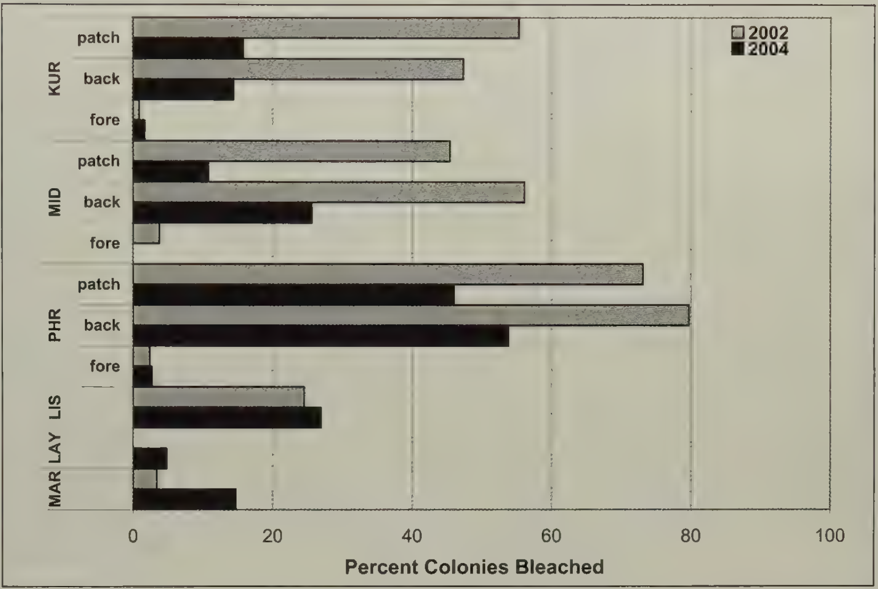


*Figure 9.3. Mean percentage of colonies with bleached tissue in belt transects surveyed in 2002 and 2004 at Kure, Midway, Pearl and Hermes Reef, Lisianski Island/ Neva Shoal, Laysan Island and Maro Reef. Minimal bleaching was seen at Gardner Pinnacles and French Frigate Shoals (not shown). Source: Kenyon et al., 2006a.*

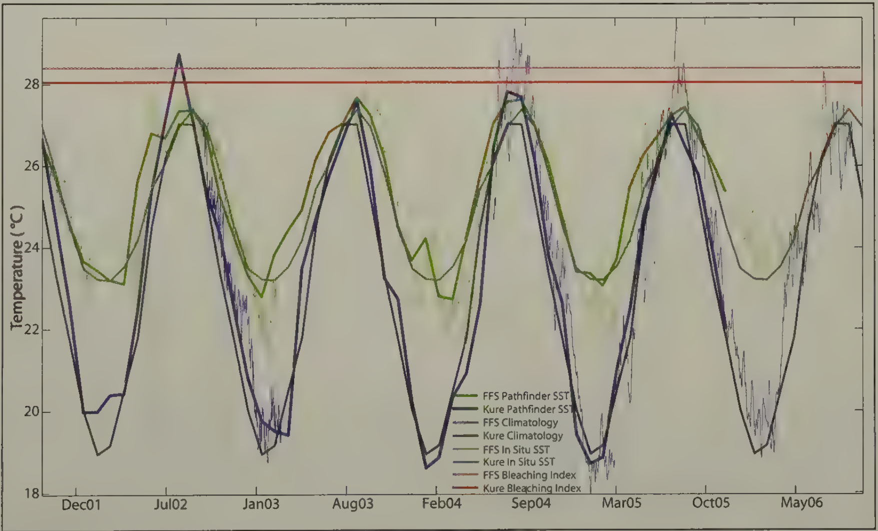


*Figure 9.4. Time series observations of* in situ *sea surface temperature (SST), Pathfinder SST, and Pathfinder SST Climatology from French Frigate Shoals and Kure Atoll. Coral Reef Watch bleaching threshold of maximum monthly mean SST plus 1°C are included for reference.* In situ *and satellite data exhibit predominantly seasonal variability, however, the annual range in temperatures is significantly greater at Kure (8-11°C) than at French Frigate Shoals (about 4-5°C).* In situ *observations indicate that temperatures exceeded the bleaching threshold at Kure in 2004, 2005 and 2006. There were no* in situ *observations of temperature during the 2002 bleaching event at Kure. Source: Brainard et al., in prep.*

lationship, which is critical to the nutrient recycling that is thought to explain the high productivity of coral reefs (Hoegh-Guldberg, 2004). Although recent research has shown that algal-dominated areas occur naturally on many healthy Pacific reefs systems (Vroom et al., 2006), macroalgal overgrowth of coral-dominated areas as the result of anthropogenically derived activities indicate decreased ecosystem health, and may result in decreased accumulation of calcium carbonate, and impacts to the reef fauna that depend on the structural complexity provided by corals. Increasing temperatures associated with climate change are likely to increase the frequency and magnitude of coral bleaching events.

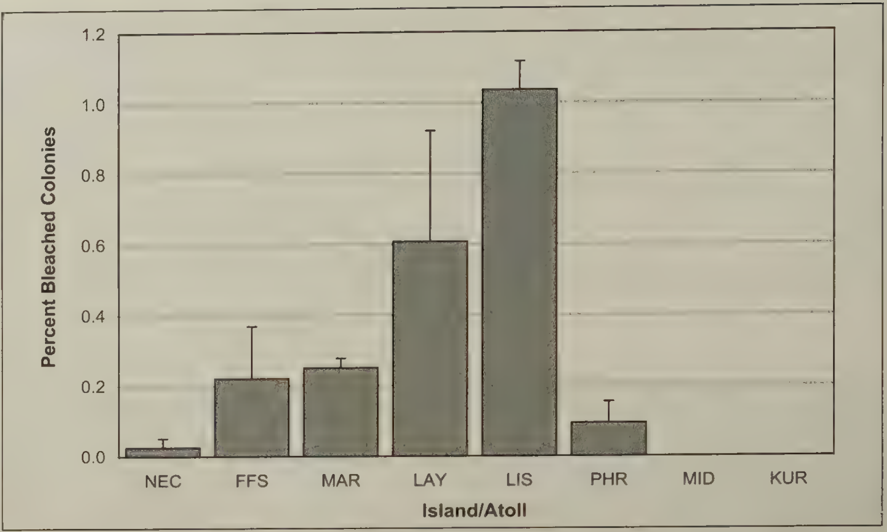


*Figure 9.5. Mean percentage (±SE) of colonies with bleached tissue on belt transects surveyed in 2006. Source: PIFSC-CRED unpub. data; Brainard et al., in prep.*

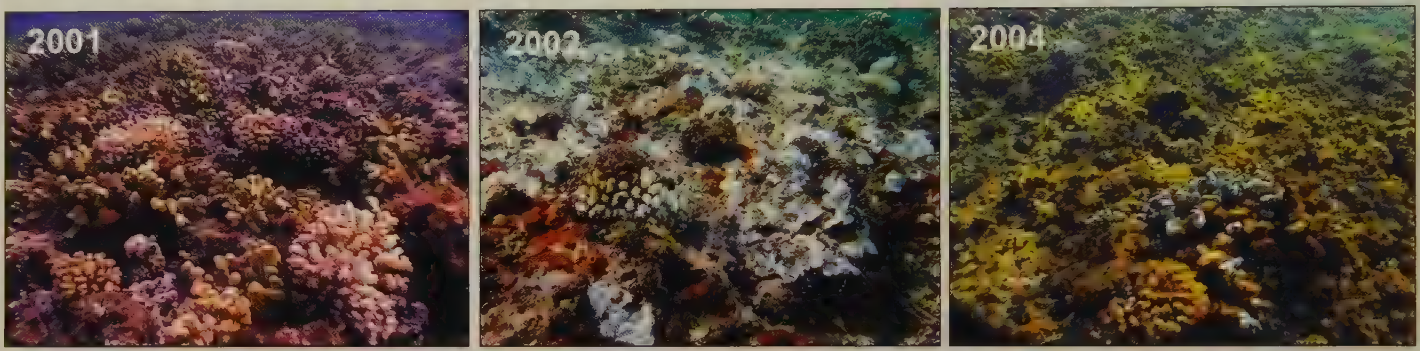


*Figure 9.6. Phase shift on a patch reef at Kure Atoll from a benthos dominated by coral to one dominated by algae after a bleaching event in 2002. From left to right: 2001, bleaching in 2002 and 2004. Photos: J. Kenyon.*

## Diseases

In 2003, baseline coral disease surveys were conducted at 73 permanent monitoring sites throughout the NWHI and these sites have since been surveyed annually. Ten disease states have now been documented in the four major genera of coral (*Porites*, *Montipora*, *Pocillopora*, *Acropora*) on the reefs of the NWHI with *Porites* trematodiasis being the most commonly found disease (Aeby, 2006; Figure 9.7). Levels of disease appear stable through time with the exception of *Acropora* white syndrome (AWS) at French Frigate Shoals. This disease was first discovered at one reef in 2003 (Aeby, 2005) and has now spread to numerous reefs within French Frigate Shoals. Ongoing studies have found the disease to be lethal to *Acropora*. Analysis of 41 marked colonies having AWS revealed partial to total mortality in 97.6% of the colonies after one year (Figure 9.8; Aeby and Work, in prep).

*Acropora* growth anomaly (AGA) is another disease of concern that is being investigated at French Frigate Shoals. AGA is a progressive and lethal disease. After one year, five of eight marked colonies (62.5%) showed an increased number of growth anomalies and 57.1% of the colonies showed tissue death over the growth anomalies, indicating the lethal effects of this disease. It was also found that this disease significantly reduces the reproductive output of coral colonies (Aeby and Work, in prep.).

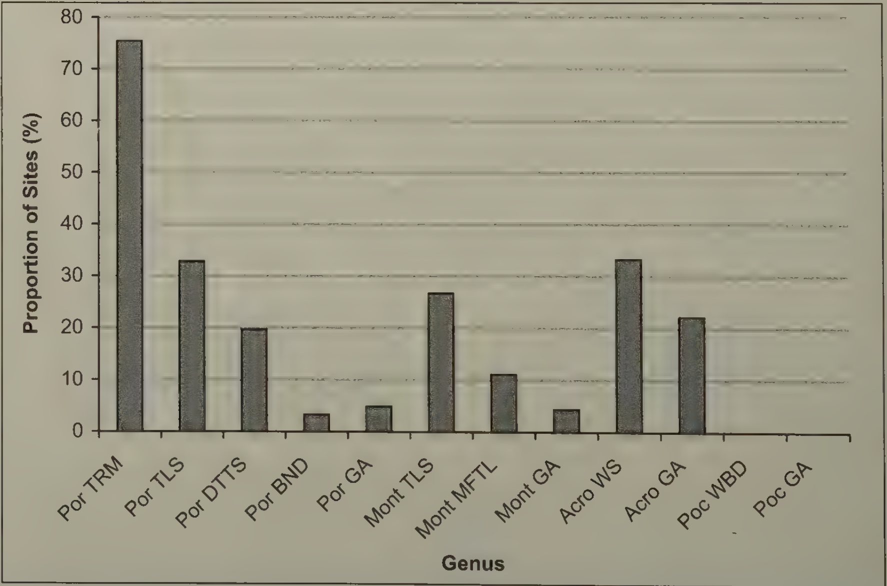


*Figure 9.7. Frequency of occurrence of different coral diseases within the NWHI. Por=Porites, Mont=Montipora, Acro=Acropora, Poc=Pocillopora, TRM= trematodiasis, TLS=tissue loss syndrome, DTTS=discolored tissue thinning syndrome, BND=brown necrotizing disease, GA=growth anomaly, MFTL=multifocal tissue loss, WS=white syndrome, WBD=white band disease. Source: G. Aeby, unpub. data.*

Diseases in marine ecosystems are not only limited to corals. In September 2005, two cases of Coralline Lethal Orange Disease (CLOD) were discovered at Maro Reef (Figure 9.9; Aeby, 2007). This disease is caused by a bright orange bacterium, which kills crustose coralline algae (CCA; Littler and Littler, 1997). It is found predominantly in the South Pacific, and this first report of CLOD in the Hawaiian Islands represents a range extension for this disease. CCA are an important component of the shallow coral reef environment because they act as binding agents that fortify the structural integrity of reefs. Hence, spread of CLOD within the NWHI will be carefully monitored.

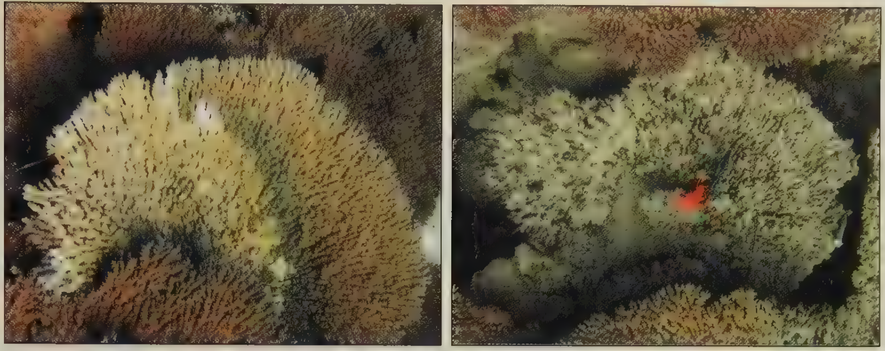


*Figure 9.8. The left photo shows* Acropora cytherea *with* Acropora *white syndrome in May 2005, and the right photo shows the same colony with complete mortality in May 2006. Photo: G. Aeby.*

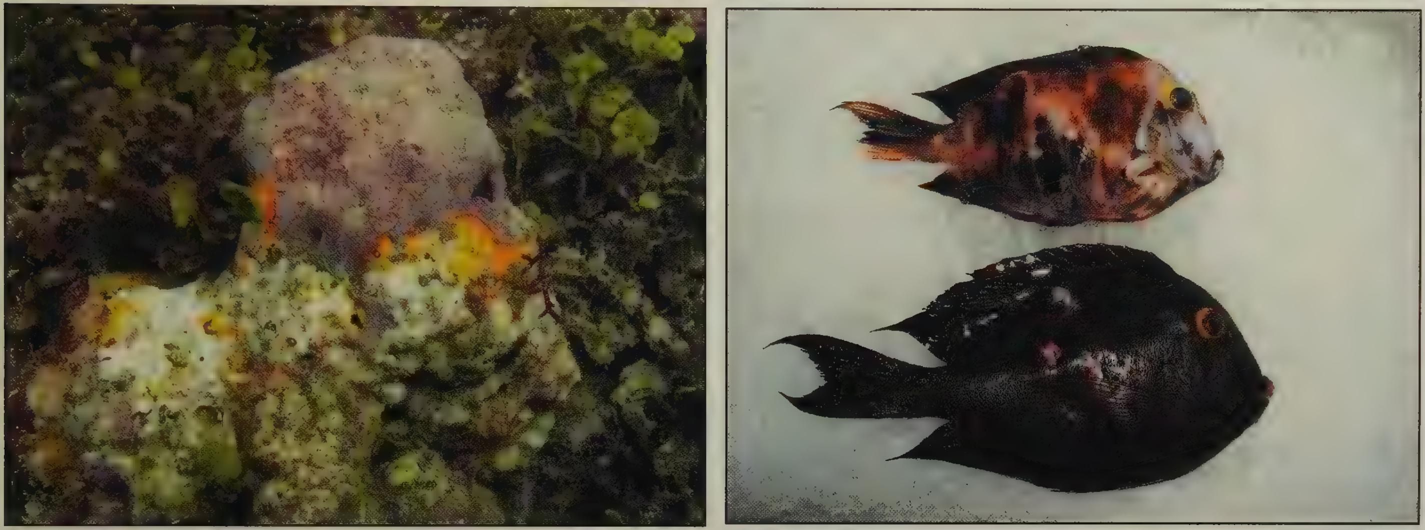


*Figure 9.9. Coralline lethal orange disease was discovered in the NWHI in September 2005 (left). Photo: G. Aeby. Goldring surgeonfish (*Ctenochaetus strigosus*) with skin disease (right). Note difference in body color and condition in diseased fish (top) and healthy fish (bottom). Photos: G. Aeby.*

A number of diseases of reef fish have now been found in the MHI (Work et al., 2003; Work and Aeby, unpub. data) and recent studies examined whether those diseases also occur in fish in the NWHI. Butterflyfishes (*Chaetodon* spp.) with skin tumors have been found in the MHI (Okihiro, 1988; Work and Aeby, unpub. data) but have yet to be documented in the NWHI (n=336 butterflyfishes examined). It has been suggested this disease is associated with poor water quality (Okihiro, 1988), which may explain its absence in the NWHI.

Other studies have examined the possibility of disease transmission between the introduced blue-lined snapper, *Lutjanus kasmira* (ta'ape), and co-occurring native goatfish species (*Mulloidichthys* spp.). *L. kasmira* were introduced into Hawaii in the 1950s (Randall, 1987) and spread all the way to Midway Atoll. *L. kasmira* are closely associated with certain native goatfish (Friedlander et al., 2002), potentially facilitating disease transmission between the native and introduced fish species. Goatfish from the MHI are infected with some of the same diseases as *L. kasmira* including protozoal and bacterial diseases in the kidney and spleen and nematode infection in the gut (Work et al., unpub. data). These same diseases were found in fish in the NWHI, but at a lower prevalence.

Goldring surgeonfish (*Ctenochaetus strigosus*) in the NWHI were observed with an obvious skin discoloration (Figure 9.9). Upon external examination, these fish were found to be in poor body condition and had fins with ragged edges. The most significant histological finding in fish with pigment anomalies was excessive growth of skin cells, suggestive of cancerous lesions (Work and Aeby, in prep.).

### *Coral Endosymbiont Symbiodinium and Disease Susceptibility*

Dinoflagellates from the genus *Symbiodinium* form mutualistic associations with coral (Muscatine and Porter, 1977). The genus *Symbiodinium* contains a diverse number of genetic varieties or clades which have been shown to affect the biology of the coral host, including growth rate and tolerance to elevated SSTs (Little et al., 2004; Rowan, 2004). Genetic tests were used to determine which clade of *Symbiodinium* was present in coral hosts (Figure 9.10). At French Frigate Shoals, a significant association was found between the clade of *Symbiodinium* and the health state of coral, with corals harboring clade A showing a higher incidence of disease (Stat et al., in prep.). Clade C was primarily found in healthy *A. cytherea* colonies. Cloned and sequenced ITS2 regions from *Symbiodinium* showed that *A. cytherea* harbors *Symbiodinium* sub-clade A1. This is the first report of A1 being found within coral from the Pacific. Interestingly, the upside down jellyfish, *Cassiopea* sp., which is an introduced species to Hawaii from the Atlantic/ Caribbean (Holland et al., 2004) also harbors A1. It is likely that the clade *A Symbiodinium* found in health-compromised *A. cytherea* in the NWHI is an introduced species that accompanied *Cassiopea* sp. (Stat and Gates, 2007).

### Tropical Storms

The NWHI are rarely exposed to tropical storms and hurricanes (Figure 9.11), but are frequently impacted by large wave events, arguably among the highest of any tropical or subtropical island archipelago (Figure 9.12). During the winter months, the NWHI experience large waves exceeding 6 m, with associated wave periods as long as 25 seconds but typically closer to 8-18 seconds. These episodic events are generated from two atmospheric low pressure systems: Aleutian Lows, which are mid-latitude cyclones spawned as waves on the polar front (Graham and Diaz, 2001; Bromirski et al., 2005); and occasionally from subtropical cyclones known as Kona Lows, which generally form in the vicinity of the NWHI themselves (Caruso and Businger, 2006). Waves associated with the Aleutian Low tend to be long period swells from the northwest while the Kona Low generates extreme waves much less frequently, tending to be of shorter period from a more westerly or south-westerly direction. The vast majority of extreme wave events associated with these weather systems occur during the winter season between October and April. Between these episodic events, easterly trade winds associated with the North Pacific Subtropical High atmospheric pressure system tend to dominate the wave conditions of the NWHI, particularly during the summer months. Trade wind conditions typically bring waves with 1-3 m wave heights and 7-11 second periods from the east. During the summer season, the North Pacific High typically lies just north of the NWHI leading to weaker pressure gradients and lighter winds in the northern portions of the archipelago and stronger pressure gradients and associated trade winds in the southern portions. Long period swell generated during the summer months from southern-hemisphere storms generally decrease in energy from the MHI to the northwest along the archipelago (Rooney et al., in press).

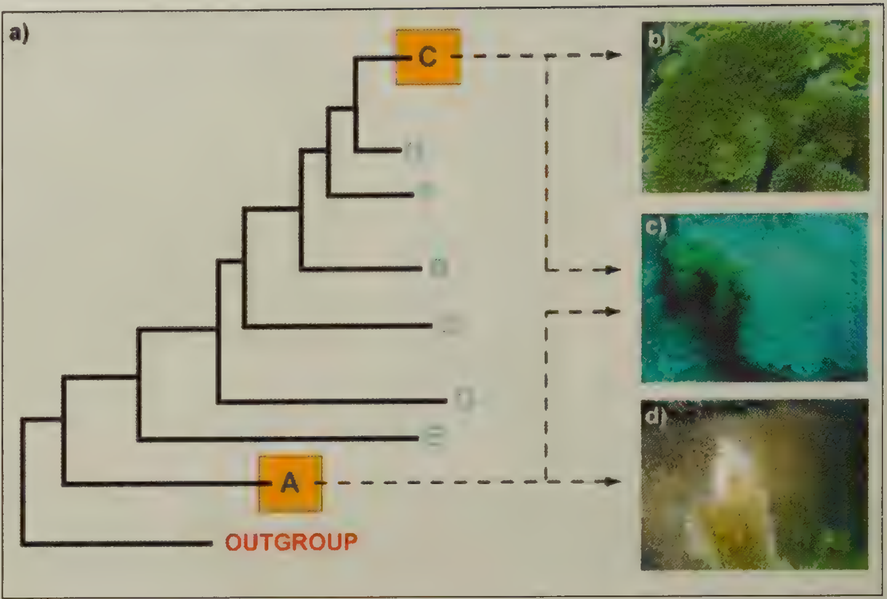


Figure 9.10. A) Phylogeny of Symbiodinium, B) healthy A. cytherea, C) A. cytherea with abnormal phenotype and blue pigmentation, and D) A. cytherea with active tissue loss. Source: Stat and Gates, unpub. data.

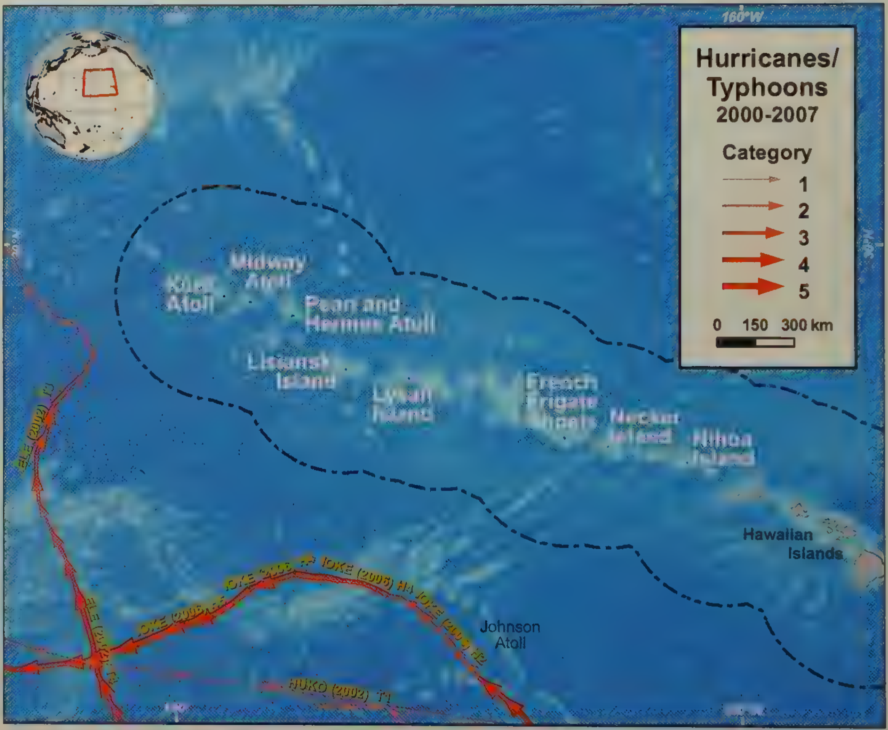


Figure 9.11. Path and intensity of tropical cyclones passing near the Hawaiian Archipelago from 2000-2007. Storm name and year are labeled on each track. Map: K. Buja. Source: http://weather.unisys.com/hurricane/.

### *ENSO/El Niño*

ENSO is an interannual (about 2–8 years) global climate phenomenon that results from the large-scale coupling of atmospheric and oceanic processes which creates significant temperature fluctuations in the tropical surface waters of the Pacific and other oceans. The two distinct ENSO signatures in the Pacific Ocean are known as El Niño and La Niña.

During El Niño events, the Aleutian Low pressure system tends to be more intense and extend further to the south (closer to the NWHI), thereby producing stronger winds, larger waves and cooler water temperatures in the NWHI (Bromirski et al., 2005). Positive ENSO signatures appear to correlate with southern extensions of the North Pacific subtropical front (Leonard et al., 2001; Rooney et al., in press; Figure 9.13).

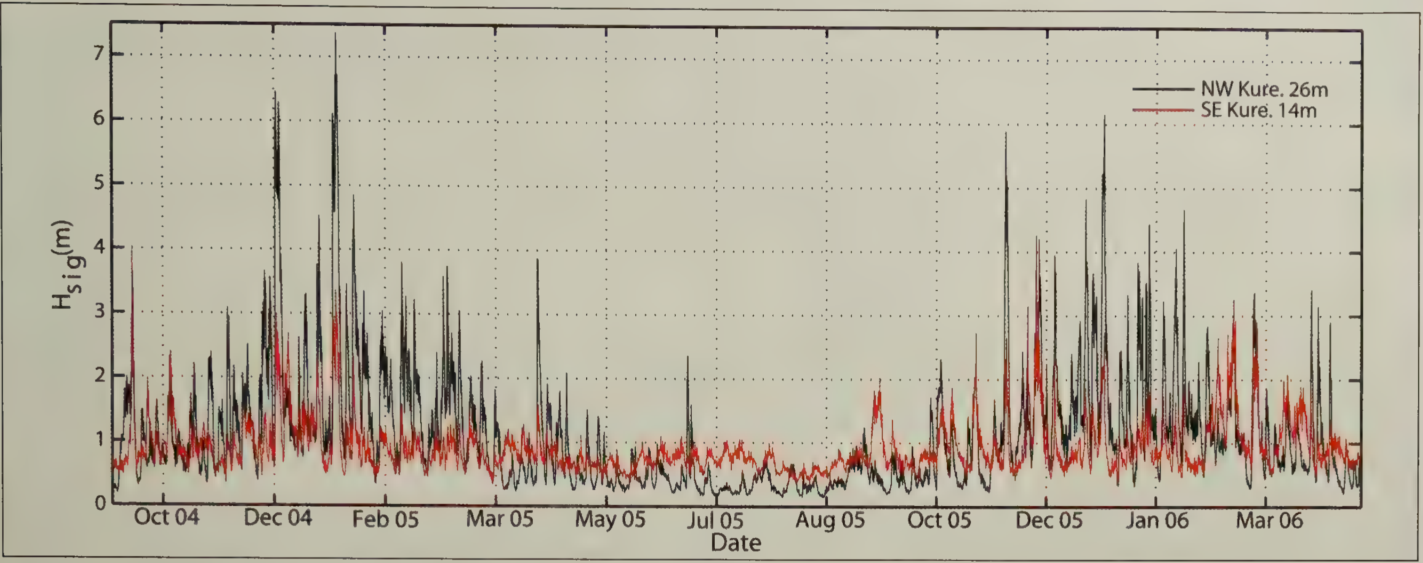


*Figure 9.12.* In situ *wave data from September 2004 to May 2006 from the northwest (black) and southeast (red) sides of Kure Atoll. Data shows significant increases in wave heights during the winter months, especially on the northwestern facing side of the atoll. Source: PIFSC-CRED, Brainard et al., in prep.*

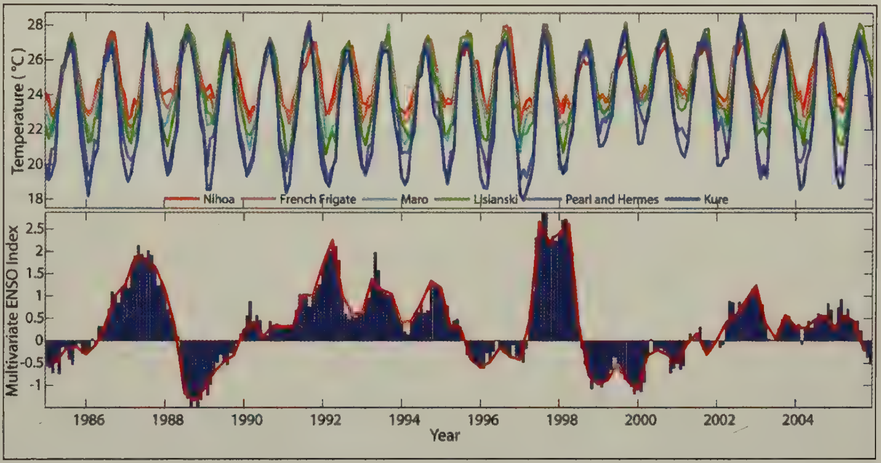


*Figure 9.13. Relationship between NOAA Pathfinder SST at Nihoa, French Frigate Shoals, Maro Reef, Lisianski, Pearl and Hermes, and Kure (top) and the Multivariate ENSO Index (MEI; bottom) from 1985-2006. Positive/negative values of the MEI indicate El Niño/La Niña conditions, respectively. Source: Brainard et al., in prep.*

## Coastal Development and Runoff

A century ago, coastal development in the NWHI consisted of guano mining at Laysan Island and the establishment of the Commercial Pacific Cable Company at Midway. The Navy occupied Midway, French Frigate Shoals, and to a lesser degree Pearl and Hermes during the first half of the 20th century. The U.S. Coast Guard (USCG) also constructed Long-Range Aid to Navigation (LORAN) stations after World War II at Kure and French Frigate Shoals and operated them for several decades. Since the closure of Navy and USCG facilities, coastal development activities have been limited to small-scale conversion of abandoned USCG buildings on Tern Island (French Frigate Shoals) and Green Island (Kure) to biological field stations.

The only recent coastal construction has been the repair of the seawall protecting Tern Island's small runway and buildings, and construction of a small boat ramp at French Frigate Shoals in 2004. This construction was needed to halt the erosion of the island and to eliminate the risk of injury and death to endangered monk seals, threatened green sea turtles and migratory seabirds. Current human population levels are limited to a few agency staff, volunteers and maintenance contractors at field stations operated at Laysan, French Frigate Shoals and Midway year round and at Kure, Lisianski, and Pearl and Hermes, seasonally.

## Coastal Pollution

Past uses of the NWHI have left a legacy of modification and contamination on French Frigate Shoals, Midway Atoll, Pearl and Hermes Atoll and Kure Atoll from human activities including guano mining, fishing camps, USCG LORAN stations, U.S. Navy bases and various military missions. Contamination at all of these sites includes offshore and onshore contaminated debris, such as batteries (lead and mercury), transformers with polychlorinated biphenyls (PCBs), capacitors and barrels.

Uncharacterized, unlined landfills remain at some islands. Kure Atoll and French Frigate Shoals have point sources of PCBs due to former LORAN stations. While the USCG has undertaken cleanup actions at both sites, elevated levels of contamination remain in soils, nearshore sediment and biota (USCG, 2003). Due to the potential interaction with monk seals and turtles, the U.S. Environmental Protection Agency (EPA) and the U.S. Fish and Wildlife Service (USFWS) are working to identify resources to reduce or eliminate the remaining contamination on Tern Island (French Frigate Shoals). Studies conducted by the USFWS, USCG, U.S. Navy and the University of Hawaii have documented contamination in soil, sediment, and biota at French Frigate Shoals, Kure and Midway. Direct impacts to Black-footed albatrosses (*Phoe-*

*bastria nigripes*) in the form of reduced hatching success have been linked to high organochlorine levels (Ludwig et al., 1997). Finkelstein et al. (2007) found a correlation between elevated levels of organochlorines and mercury and impaired immune function in Black-footed albatrosses, a species that is currently the subject of a petition to be listed as endangered or threatened under the U.S. Endangered Species Act, as amended (72 FR 57278).

Pollution generated by past and present human activities, from sea-based and land-based sources, continues to stress the NWHI ecosystem. Emergency response mechanisms and ongoing cleanup and restoration activities must be maintained and enhanced to address these issues.

## Tourism and Recreation

Recreational activities in the PMNM are limited to the Midway Atoll Special Management Area (SMA). Since 1995, USFWS has been strongly committed to welcoming visitors to Midway Atoll. This is the first and only remote island national wildlife refuge in the Pacific to provide the general public with an opportunity to learn about and experience these unique ecosystems. With the establishment of the PMNM, Midway Atoll National Wildlife Refuge (NWR) will allow visitors to learn about and enjoy a small portion of the largest fully protected marine managed area in the world.

A regularly scheduled visitor program operated on Midway Atoll until early in 2002, but ended when the concessionaire left the atoll. Between 2005 and 2007, minimal tourism and recreational activities occurred at Midway due to a lack of viable visitor access and limited ability to host visitors on-site. A limited number of tourists visited Midway Atoll NWR and the Battle of Midway War Memorial aboard small cruise ships that stopped at the atoll for less than a 24-hour period en route to other destinations. Visitors were provided guided tours of the NWR resources and the Battle of Midway Memorial, located on Eastern Island. In June 2007, Midway celebrated the 64th anniversary of the Battle of Midway with limited visits by chartered plane and a small cruise ship.

The USFWS recently completed an Interim Visitor Services Plan for Midway Atoll. For the next four years (2008-2011) visitor programs will operate from November through July, which coincides with the albatross season on Midway. The months of August through October are reserved primarily for planned construction and major maintenance activities. Plans are to slowly expand the visitor services over the next five years with accommodations limited to no more than 30 visitors at a time in the next three years and the ability to accommodate no more than 50 visitors at a time within the next five years. A range of options for visitor activities (such as wildlife viewing and snorkeling excursions) is being considered but must be compatible with maintaining wildlife health. Based on the results of the evaluation required in the Monument Management Plan's Midway Atoll Visitor Services Action Plan, other operational designs may be instituted in the longer term.

## Fishing

In recent years, fishing and other resource extraction in the NWHI have been mostly limited to two commercial fisheries: the ongoing NWHI bottomfish fishery, and the now-closed NWHI lobster trap fishery. The bottomfish fishery has targeted about a half-dozen species of deep-slope (generally >140 m) Eteline snappers (family Lutjanidae) and one endemic species of grouper (family Serranidae) out of a total of a dozen common Bottomfish Management Unit Species (BMUS; WPFMC, 2004).

The bottomfish fishery is divided into two management zones (Mau, Hoomalu), partly in order to distinguish between short- and long-duration fishing trips (Figure 9.14). Between 1996 and 2004, the Mau zone bottomfish catch was dominated by shallow-water species such as uku (jobfish, *Aprion virescens*, 39%), butaguchi (thicklipped jack, *Pseudocaranx dentex*, 14%), but also included the deepwater species opakapaka (pink snapper, *Pristipomoides filamentosus*, 13%), hapuupuu (*Epinephelus quernus*, 13%), and onaga (red snapper, *Etelis coruscans*, 8%). The deepwater species, onaga and opakapaka, accounted for 53% of the Hoomalu catch, followed by hapuupuu (15%; Figure 9.15).

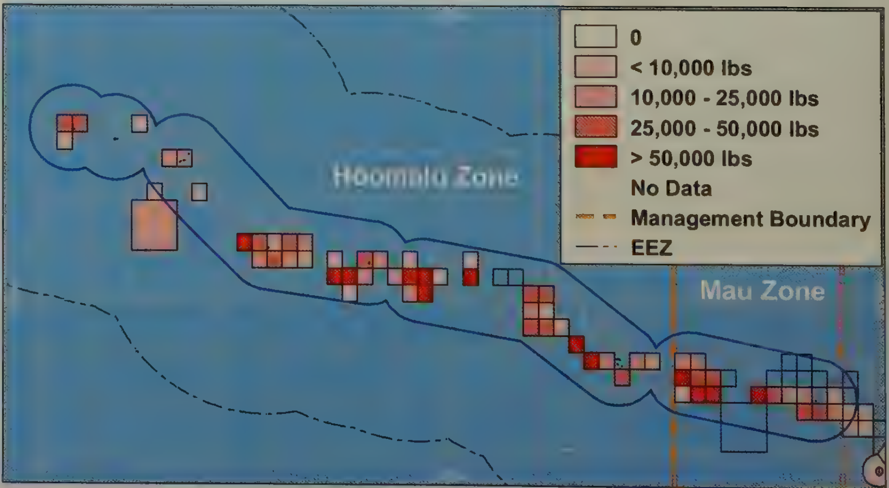


*Figure 9.14. Total commercial bottomfish landings from 1996 to 2002. Data in several cells can not be shown due to confidentiality concerns. Data: DAR; Ehler, 2004.*

The average annual reported landings of bottomfish in the NWHI between 1984 and 2003 were 336,000 lbs (±235,500 SD; NOAA, 2006). Of this, the Mau zone averaged 107,130 lbs (±53,890 SD) or 32% while the average catch in the Hoomalu zone averaged 228,730 lbs (±63,030 SD) or 68% (Figure 9.14). Landings are concentrated at a small number of locations in the Mau and Hoomalu zones (Figure 9.14). In 2003, the gross reported revenues for the Mau zone were $611,000 and $674,000 for the Hoomalu zone (Ehler, 2004). In 2003, the number of vessels participating in the two zones remained the same from the previous year, but there were substantial changes in the number of fishing trips (NOAA, 2006). In 2003, Mau zone trips decreased by 51% resulting in a 29% drop in landings from the previous year. The number of trips in the Hoomalu zone increased by 50% in 2003, resulting in a 29% increase in landings.

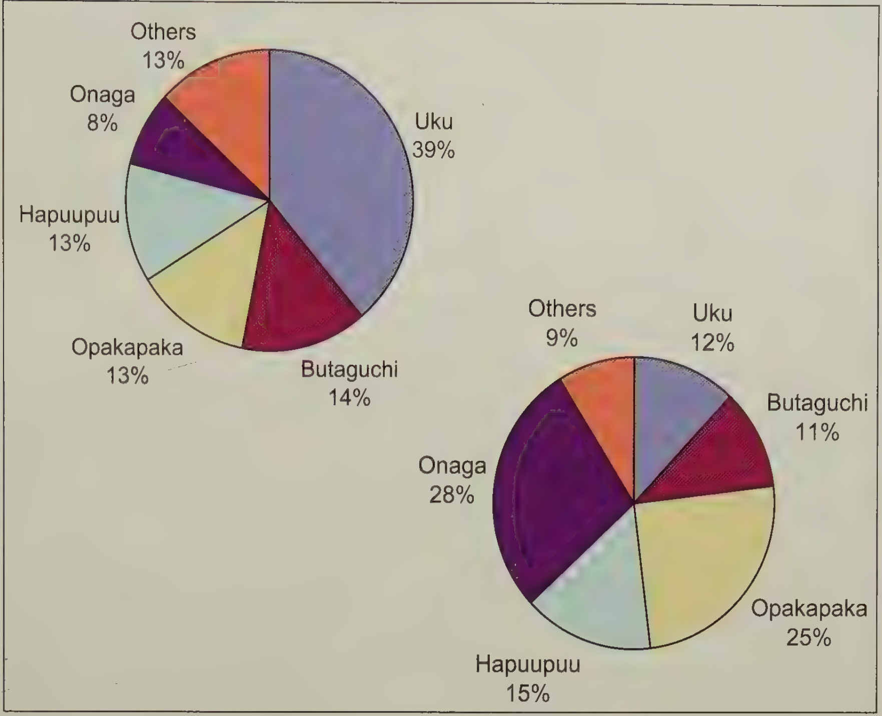


*Figure 9.15. Average species composition (1996-2004) of bottomfish catches from the Mau (top left) and Hoomalu zones (bottom right) in the NWHI. Source: Kawamoto and Gonzales, 2005; WPRFMC, 2005.* **NOTE:** *see text for scientific and common names.*

With the initial designation of the NWHI Coral Reef Ecosystem Reserve in 2000 and now PMNM, fishing activity in the NWHI has been on the decline. Proclamation 8031 allows commercial fishing by federally permitted bottomfish fishery participants that have valid permits until mid-2011 (FR 36443, June 26, 2006), which amounts to a maximum of eight vessels that are currently permitted to fish within the monument. Significant work was undertaken prior to the designation of the monument in response to previously issued Executive Orders that created the reserve in 2000. This fishery operates according to the management regime specified in the Fishery Management Plan for Bottomfish and Seamount Groundfish Fisheries in the Western Pacific Region. The management regime includes several precautionary measures that minimize potential effects of this fishery. The bottomfishery participants do not operate in the presence of the Hawaiian monk seals, and the annual harvest limit for the eight vessels is 300,000 lbs.

A multiyear project was designed to assess the impacts of commercial bottomfishing in the Raita and West St. Rogatien (e.g., first bank west of St. Rogatien) Reserve Preservation Areas (RPAs), based on the 2000 Executive Order which stipulated that after five years, bottomfishing will only be allowed in these two RPAs, "if it is determined that continuation of such activities will have no adverse impact on the resources of these banks." In 2001, known fishing sites in each RPA were surveyed using the *Pisces V* submersible and the RCV-150 remotely operated vehicle (ROV) operated by the Hawaii Undersea Research Laboratory (Kelley and Moffitt, 2004). During 2002 and 2003, a set of three submersible dives were conducted on each study site to obtain data on: the abundance and size of bottomfish targeted by fishermen; amount of fishing debris present at the sites; and the types and abundance of benthic invertebrates and other fish species that could be impacted by fishing activities. The data obtained during this study indicate that impacts resulting from bycatch, lost fishing gear, discarded trash and damage to benthic invertebrates such as attached cnidarians, were relatively low (Kelley and Moffitt, 2004). Removal of one of the two primary target species, the onaga (red snapper, *Etelis coruscans*) could be effecting the population at Raita Bank, although previous estimates of maximum sustainable yield indicate that the number being taken is sustainable. However, due to problems with interpreting the catch data, changes in the rules and data reporting methods are recommended for these and other RPAs.

The number of fishers actively working the banks is relatively low (four to five boats) and the amount of gear and debris discarded on the banks is also low. The substrate on each of the banks is relatively barren, with tops being primarily covered with rhodoliths while the slopes are mostly featureless carbonate rock and sediment. Based on limited exploratory surveys, reef-building corals were not found at bottomfishing depths, and other types of cnidarians, as well as sponges, urchins and sea stars were in low abundance. In general, there appears to have been very little collateral damage caused by bottomfishing at either Raita Bank or West St. Rogatien Bank (Kelley and Moffitt, 2004; Table 9.1).

*Table 9.1. Impact of bottomfishing on the Raita and West St. Rogatien Reserve Preservation Areas in the NWHI Monument. Source: Kelley and Moffitt, 2004.*

| | IMPACT |
|---|---|
| Target Species Removal | Low -------------------------♦-------High |
| Bycatch Species Removal | Low ----♦----------------------------High |
| Fishing Debris Addition | Low ----♦----------------------------High |
| Trash Addition | Low ----♦----------------------------High |
| Cnidarian Alteration | Low ----♦----------------------------High |
| Other Invertebrate Alteration | Low ----♦----------------------------High |
| Competitor Alteration | Low ----♦?--------------------------High |
| Prey Alteration | Low ----♦?--------------------------High |

With the exception of Brooks Bank, bottomfishing impacts have not been investigated on any other sites in the monument. Brooks Bank was found to have a relatively extensive bed of black coral (*Antipathes ulex*) within bottomfishing depths and black corals and large anemones (e.g., *Telmatactis* sp.), were observed in abundance on the top of Bank 66 east of French Frigate Shoals during a single submersible dive and several ROV dives on that location in 2002 (Kelley et al., unpub.). In 2003, unusual stylasterid hydrozoans were also recorded in bottomfish depths during dives investigating deepwater corals on NWHI seamounts (Baco-Taylor, unpub.). Based on these observations, it is unknown but likely that deepwater coral beds are present on other bottomfishing sites in NWHI.

## Trade in Coral and Live Reef Species

No trade in coral and live fish is permitted in the PMNM.

## Ships, Boats and Groundings

A number of factors have contributed to vessel groundings and cargo loss in the NWHI, including human error, lack of appropriate navigational practices, inaccurate nautical charts and treacherous conditions due to low lying islands, atolls, and shallow pinnacles and banks. When the 85-foot longliner *Swordman I*, carrying more than 6,000 gallons of diesel fuel and hydraulic oil, ran aground at Pearl and Hermes in 2000, vessel monitoring system technology allowed agents to track the disaster and quickly respond. Cleanup costs, which were recovered from the owner in court, exceeded $300,000.

In July 2005, the NOAA-chartered marine debris cleanup vessel M/V *Casitas* (Figure 9.16) ran aground at Pearl and Hermes Atoll. Following the removal of 33,000 gallons of fuel and oil, the 145-foot motor vessel was successfully extracted from the reef and entombed northwest of the atoll in approximately 2,200 m of water. However, the crew fleeing the sinking vessel was forced to camp on a quarantine island without "clean gear." It has yet to be determined if any invasive species came ashore with the shipwecked crew. Unified Command representatives from the USCG, state of Hawaii and Northwind Inc. (owner of the *Casitas*), in cooperation with the federal trustees USFWS and NOAA, oversaw the operation to prevent further damage to the coral reef ecosystem and islands. The preliminary injury assessment resulted in an estimate of total damaged area of reef as 1,810 m$^2$, of which 508 m$^2$ was estimated to be coral. A full injury assessment may be conducted in the near future, depending upon the outcome of negotiations between the trustees and the responsible party.

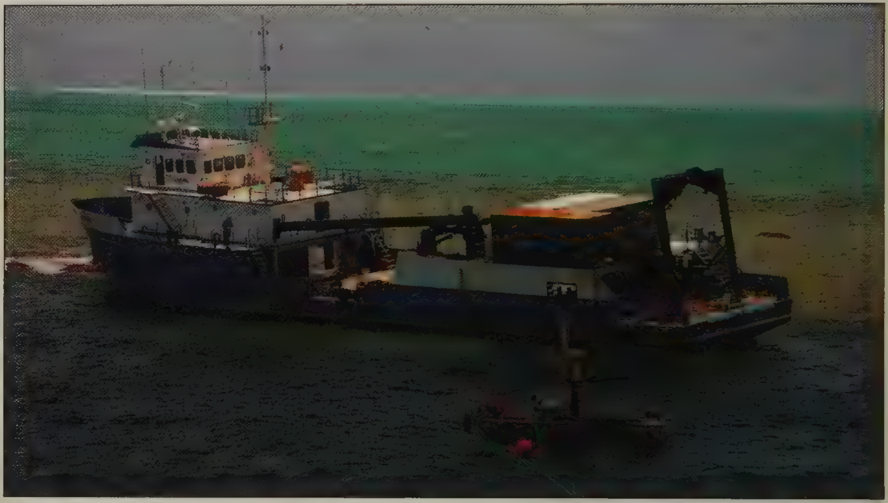


*Figure 9.16. Charter vessel M/V* Casitas *aground at Pearl and Hermes Atoll, July 2005. Photo: USFWS.*

Most vessel activity in the NWHI occurs in corridors along the island chain and across the chain between Pearl and Hermes Atoll and Lisianski Island (Franklin, in press). The vessels transiting across the chain are primarily large (about183 m), foreign-flagged commercial freighters and tankers traveling to or from major Asian and U.S. ports (Figure 9.17). Vessels traveling along the chain are primarily either commercial fishing vessels or research vessels originating from the MHI. Commercial fishing vessels from the MHI spend the most cumulative time of any vessel type in the PMNM.

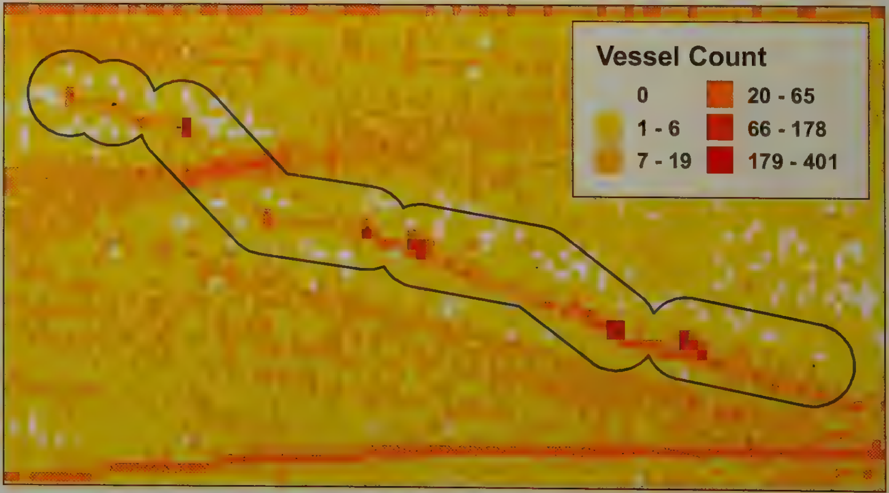


*Figure 9.17. Spatial distribution of vessels reported near and within the current boundaries of the PMNM from 1994 to 2004. Source: Franklin, in press.*

## Marine Debris

Derelict fishing gear and other marine debris threaten the near-pristine coral reef ecosystems of the NWHI, which are prone to the accumulation of floating debris due to their location in the Subtropical and Subpolar North Pacific gyres. Most of the debris consists of derelict fishing gear that can entangle and kill endangered Hawaiian monk seals, threatened green sea turtles and other wildlife. Debris can also cause physical damage to sensitive reef habitats, including corals and other benthic flora and fauna, present a hazard to navigation and may accelerate the introduction of non-native species. In an effort to reduce entanglements of Hawaiian monk seals, NOAA's Pacific Island Fisheries Science Center (PIFSC) began removing marine debris from the beaches of the NWHI in 1982. Following pilot surveys of debris in the surrounding coral reefs in 1996, PIFSC-Coral Reef Ecosystem Division (PIFSC-CRED) has led the removal of over 511 metric tons of marine debris from the reefs and beaches through a collaborative effort with other federal, state and local partners, including the PMNM, state of Hawaii, USFWS, USCG, Schnitzer Steel Hawaii, Covanta Energy and the University of Hawaii (Table 9.2, Figure 9.18). A five-year, intensive removal effort (2001–2005) supported by NOAA's Coral Reef Conservation Program (CRCP) and NOAA's Marine Debris Program enabled the PIFSC and its partners to remove a large percentage of the historical debris from the reefs of the NWHI.

*Table 9.2. Annual and cumulative amounts (kg) of derelict fishing gear and other marine debris removed from the islands and atolls of the NWHI by the multi-agency marine debris team lead by NOAA Fisheries PIFSC-CRED since 1996. Source: PIFSC-CRED.*

| YEAR | PHR | MARO | FFS | KURE | MIDWAY | LISIANSKI | LAYSAN | TOTAL |
|---|---|---|---|---|---|---|---|---|
| 1996/1997 | 2,223 | 0 | 2,145 | 0 | 0 | 0 | 0 | 4,368 |
| 1998 | 0 | 0 | 7,500 | 0 | 0 | 0 | 0 | 7,500 |
| 1999 | 8,676 | 0 | 2,145 | 0 | 9,091 | 5,444 | 0 | 25,356 |
| 2000 | 9,866 | 0 | 0 | 3,069 | 7,457 | 2,035 | 0 | 22,427 |
| 2001 | 30,501 | 0 | 5,625 | 23,516 | 0 | 830 | 1,075 | 61,547 |
| 2002 | 92,955 | 0 | 432 | 1,567 | 0 | 1,087 | 1,231 | 97,272 |
| 2003 | 79,572 | 0 | 2,245 | 1,217 | 18,694 | 3,588 | 2,154 | 107,470 |
| 2004 | 56,668 | 46,740 | 1,402 | 3,284 | 0 | 2,799 | 3,040 | 113,933 |
| 2005 | 14,281 | 10,361 | 17,793 | 2,219 | 4,899 | 1,170 | 1,084 | 51,807 |
| 2006 | 4,228 | 0 | 1,028 | 9,142 | 2,680 | 368 | 1,549 | 18,995 |
| **TOTAL** | **298,970** | **57,101** | **40,315** | **44,014** | **42,821** | **17,321** | **10,133** | **510,675** |

*Figure 9.18. Divers cutting away nets from the reef in the NWHI (left). Marine debris being loaded aboard the NOAA ship* Oscar Elton Sette *(right). Photos: PIFSC-CRED.*

In 2006, a maintenance level effort was initiated to investigate the annual accumulation rates of debris at targeted atolls. During the first year of maintenance mode, the PIFSC and its partners removed 19 metric tons of derelict fishing gear from the NWHI. Debris was observed to accumulate in greater abundance in low energy lagoonal habitats (Figure 9.19). A newly released study estimates that the annual accumulation rate is over 52 tons, which is greater than originally anticipated (Dameron et al., 2007). This indicates that the current level of effort is not sufficient to keep up with the annual rate of accumulation, and future efforts need to focus on bridging this gap. In addition, ongoing efforts to develop at-sea debris detection and mitigation technologies aimed at removing derelict fishing gear from the open ocean before it can impact coral reef ecosystems are continuing. Finally, efforts in outreach, education and partnership-building need to be increased to address this issue locally as well as with Pacific Rim communities that share the responsibility for this marine debris.

Morishige et al. (2007) documented a significantly higher amount of marine debris coming ashore in the NWHI during El Niño periods compared with La Niña conditions over a 16-year period (Figure 9.20). Volunteers with the USFWS tabulated, collected and removed more than 52,000 pieces of debris since 1990 from the shores of the Hawaiian Islands National Wildlife Refuge's Tern Island station, located at French Frigate Shoals. More than 70% of the debris removed was made of plastic and included buoys, bottles and cigarette lighters. Evidence suggests that the increase in marine debris on the shores of the NWHI is a result of the southward movement of the Subtropical Convergence Zone, which tends to concentrate marine debris in the NWHI, particularly during El Niño periods.

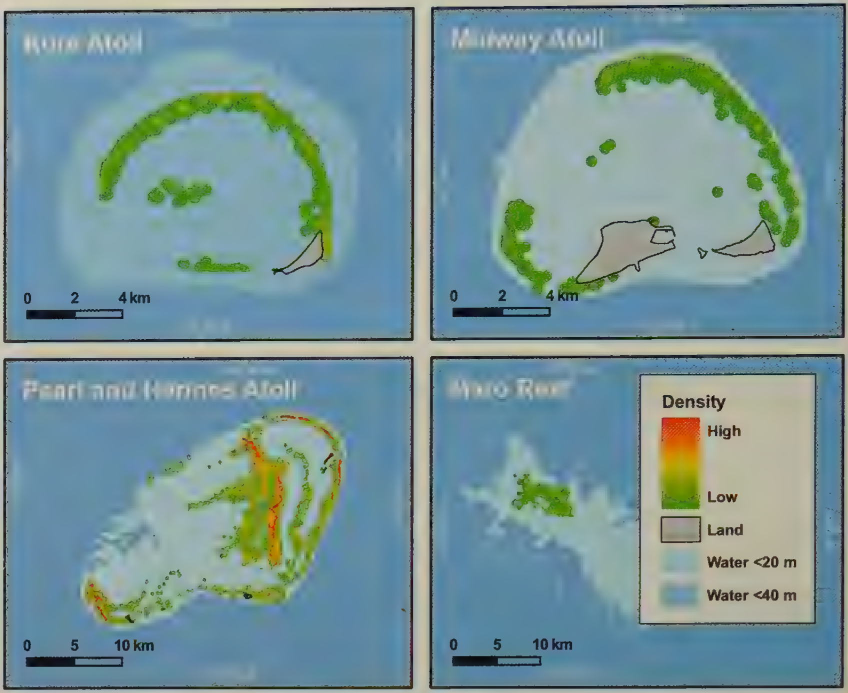


*Figure 9.19. Maps depicting numerical densities of debris sites marked by GPS following discovery. Dark red in the monochromatic color ramp represents the highest debris densities. Buffered survey areas are shown for each location with green lines. Data source: Dameron et al., 2007; map: K. Buja.*

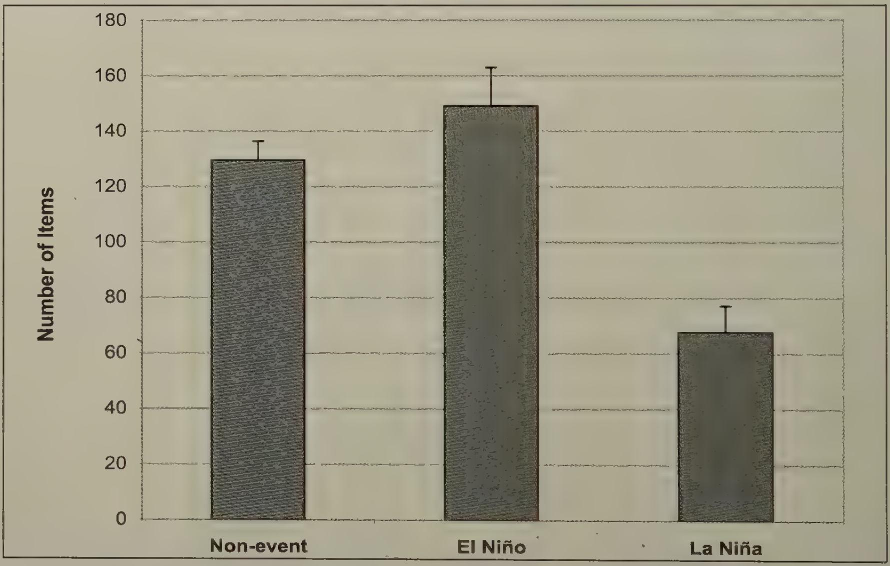


*Figure 9.20. Mean number of items (±SE) deposited on beaches surveyed on Tern Island, French Frigate Shoals during El Niño (n=92), La Niña (n=33) and non-events (n=258) from 1990-2006. Debris deposition during La Niña events was significantly less than in El Niño and non-events (p<0.05). Source: Morishige et al., 2007.*

## Aquatic Invasive Species

In sharp contrast to the MHI, which harbors at least 287 introduced and cryptogenic (unknown origin) invertebrate species, only five introduced invertebrates have become established and two more have been recorded but do not appear to be established in the NWHI (Godwin et al., 2006; Friedlander et al., 2005; Eldredge, 2005). Not surprisingly, the majority of invertebrate introductions are found at Midway Atoll and French Frigate Shoals, which have long histories of anthropogenic activity. At Midway, the four invertebrate introductions include the hydroid, *Pennaria disticha*, two bryozoans, *Amathia distans* and *Schizoporella errata*, and the barnacle, *Chthamalus proteus* (Figure 9.21). Only two introduced species, the hydroid *Pennaria disticha* and the snapper, *Lutjanus kasmira*, are found throughout the NWHI archipelago (Godwin et al., 2006).

Populations of non-indigenous marine species that have already colonized areas of the MHI represent the most likely source of invasive species in the NWHI based on the proximity and pattern of ship movements associated with the MHI (Godwin et al., 2006). Marine debris has been shown to have the ability to transport non-indigenous species to the NWHI (Godwin et al., 2006). Modes of transport such as derelict fishing nets are problematic to manage but the impact of other debris, such as Fish Attraction Devices (FAD) deployed by the state of Hawaii, can be minimized (Godwin et al., 2006).

Since 2000, annual NWHI Reef Assessment and Monitoring Program (RAMP) cruises have conducted species level Rapid Ecological Assessment (REA) surveys to characterize the marine flora and fauna of the NWHI, including examination of the presence or absence of alien species. Additionally, NOAA's PIFSC-CRED have used towed-diver methodologies on a biennial basis to survey benthic composition and abundance and distribution of large fishes (>50 cm total length) and key macroinvertebrates over large stretches of shallow water marine ecosystems. These surveys also help document outbreaks of alien and native invasive species. Of the nine currently established marine alien species in the NWHI (one alga, five invertebrates and three fishes), the population ranges for all except the hydroid, *P. disticha*, have remained static from 2005 to present (Friedlander et al., 2005; Godwin et al., 2006). *P. disticha* has now been recorded from Nihoa to Kure Atoll (S. Godwin, pers. obs.).

In 2005, international press coverage caused a minor panic over the potential spread of the red, invasive alga, *Hypnea musciformis* to the NWHI. The species was first recorded from deep water (>30 m) at Mokumanamana (Necker Island) in 2002, and one small individual was found as part of a drift assemblage at Maro Reef. From 2002 through 2004, small sprigs of the alga were commonly recorded on lobster traps at Mokumanamana brought up from depths of 30-90 m, but caused no immediate concern among algal biologists working in the NWHI. Suddenly, in spring to early summer of 2005, pounds of *H. musciformis* (Figure 9.22) began to appear on lobster traps at Mokumanamana, fostering concern about a large-scale epidemic of this nuisance alga. The algal bloom received international attention through numerous media outlets, and a special cruise was organized in autumn 2005 by PMNM to investigate the problem. Interestingly, no *H. musciformis* was discovered at Mokumanamana during the cruise, and continued investigations of algae associated with lobster traps in 2006 have failed to find any significant population blooms other than a few small individuals similar to those documented in 2002 through 2004. During annual NWHI RAMP cruises between the years 2000-2006, *H. musciformis* was not observed in shallow water reef environments anywhere in the NWHI, suggesting that the species currently appears to be restricted to deeper water habitats beyond the range of divers at Mokumanamana. No other alien or invasive algae have been reported from the NWHI.

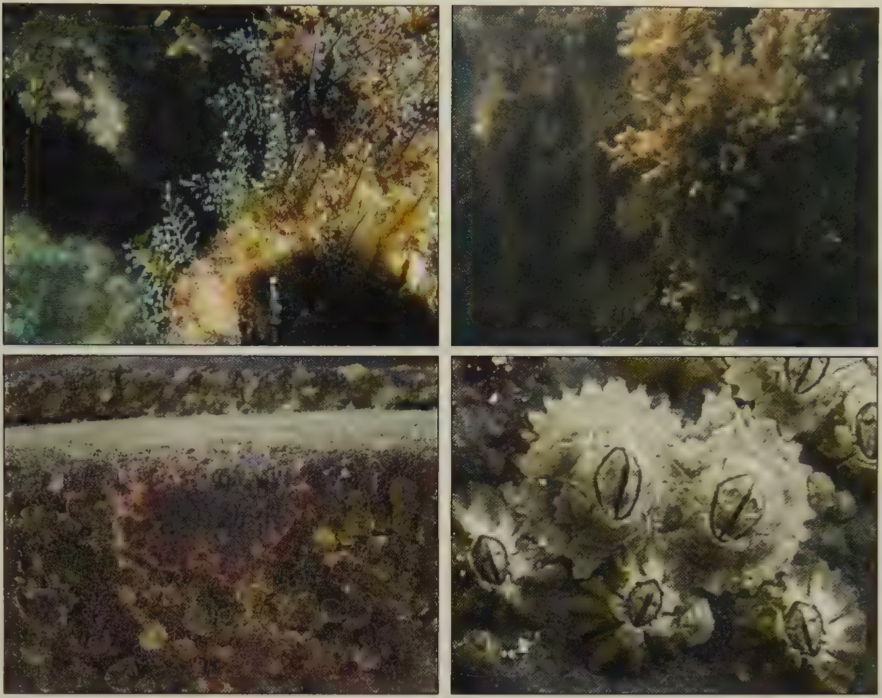


*Figure 9.21. Top left to bottom right, introduced invertebrates at Midway include a hydroid,* Pennaria disticha, *two bryozoans,* Amathia distans *and* Schizoporella errata, *and a barnacle,* Chthamalus proteus. *Photos: S. Godwin, J. Leonard, C. Zabin.*

The green alga *Caulerpa taxifolia* is a native organism to waters of the Hawaiian Archipelago and has never shown invasive tendencies in any environment in the NWHI. Despite the concerns caused by *C. taxifolia* in areas of accidental introduction (Australia, California and the Mediterranean Sea) where it can rapidly overgrow miles of coastline, individuals of native *C. taxifolia* in the NWHI usually grow in discrete patches under overhanging carbonate ledges and have never been observed to overgrow coral species or other biological organisms.

## Security Training Activities

No military security training activities occur in the PMNM.

## Offshore Oil and Gas Exploration

No offshore oil and gas exploration occurs in Hawaiian waters.

## Others

### *Coral Predators: Crown-of-thorns Sea Star (Acanthaster planci) and Drupella*

The crown-of-thorns sea star (COTS; Figure 9.22) and *Drupella* spp. snails are both corallivores that have caused significant coral damage in areas of the Indo-Pacific. They are being monitored on the reefs of the NWHI during REA and towed-diver surveys. Towed-diver surveys report COTS to be present on the reefs of the NWHI but to occur at relatively low levels (average=0.65 COTS/km; PIFSC-CRED, unpub. data; ). During annual benthic monitoring surveys it was found that the frequency of occurrence (number of sites with animals or feeding scars/total sites surveyed) for *Drupella* was low (3% in 2004, 15.4% in 2005; Aeby, unpub. data). *Drupella* were usually found feeding at the base of branches of *Pocillopora meandrina*. For COTS, frequency of occurrence was also moderately low with reports of COTS observed at 4.5% of the REA monitoring sites in 2004, and 28.2% in 2005 (Aeby, unpub. data). COTS were usually found as single animals and not in aggregations.

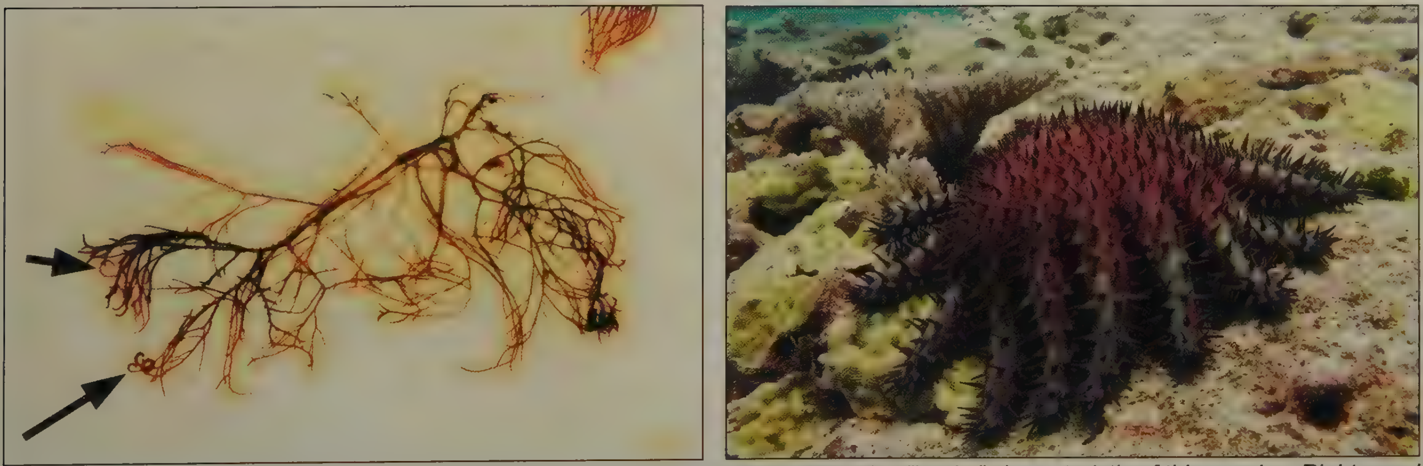


*Figure 9.22. Left panel shows* H. musciformis, *with arrows pointing out the distinctive "hooks" characteristic of this species. Right panel shows a COTS at French Frigate Shoals. Photos: P. Vroom and J. Kenyon.*

## CORAL REEF ECOSYSTEM—DATA-GATHERING ACTIVITIES AND RESOURCE CONDITION

The monitoring programs that are currently collecting data in the NWHI are listed in Table 9.3. Many locations where monitoring has recently occurred are shown in Figure 9.23.

*Table 9.3. Long-term monitoring programs in the NWHI. Source:* PIFSC-CRED.

| MONITORING PROGRAM | OBJECTIVES | YEAR EST. | FUNDING | AGENCIES |
|---|---|---|---|---|
| Fishery monitoring and economics program | Fisheries catch and effort statistics | 1948 | NOAA | PIFSC, DAR |
| Marine turtle research program | Monitor selected sea turtle breeding sites | 1973 | NOAA, FWS | FWS, PIFSC |
| Seabird monitoring | Monitoring selected nesting seabird species | 1978 | FWS | USFWS, PIFSC |
| Fishery independent lobster monitoring | Monitor lobster using fisheries-independent sampling | 1983 | NOAA | PIFSC |
| Marine mammal research program | Monitor and assess subpopulations | 1985 | NOAA | PIFSC, FWS |
| Marine debris program | Rates of marine debris accumulation | 1996 | NOAA | PIFSC-CRED, UH, FWS, DAR, USGS |
| Reef assessment and monitoring program | Monitor and assess reef communities via integrated ecosystem science | 2000 | CRCP | PIFSC-CRED, FWS, numerous collaborators |
| Oceanography and water quality program | Spatial and temporal observations of physical and chemical oceanographic conditions and processes influencing reef health. | 2000 | NOAA | PIFSC-CRED, UH |
| Coral monitoring | Monitoring corals at permanent sites | 2000 | HCRI, FWS | FWS, PIFSC-CRED, CRCP |
| Connectivity and ecosystem health | Examine connectivity, ecosystem health and genetic structure | 2005 | NMSP | HIMB |

CRCP – NOAA's Coral Reef Conservation Program
PIFSC-CRED - Coral Reef Ecosystem Division
DAR - Hawaii DLNR, Division of Aquatic Resources
FWS - U.S. Fish and Wildlife Service
HCRI - Hawaii Coral Reef Initiative
HIMB - Hawaii Institute of Marine Biology
NMSP - National Marine Sanctuary Program
NOAA - National Oceanic and Atmospheric Administration
NOS - National Ocean Service
PIFSC - Pacific Islands Fisheries Science Center
UH - University of Hawaii
USGS – U.S. Geological Survey

## WATER QUALITY AND OCEANOGRAPHIC CONDITIONS

The health, functioning and biogeography of the coral reef ecosystems of the NWHI are primarily controlled by the oceanographic processes and conditions, both physical and chemical, to which they are exposed. The broad and diverse biological communities comprising these ecosystems, including fishes, corals and other invertebrates, algae, turtles, seabirds and marine mammals, is significantly influenced by spatially and temporally-varying ocean currents, waves, temperature, salinity, turbidity, nutrients, and other measures of water quality and oceanographic conditions. As these conditions change, so do the condition, distribution, abundance and species diversity of reef communities. Though these processes vary over a diverse range of time scales, from seconds (individual waves), to tidal and diurnal, to seasonal, to interannual (multiple years), to decadal, to long-term climate changes, the biogeography of the reef communities has generally evolved to accommodate all of the shorter-term scales. Longer-term changes, particularly those related to climate, are of particular concern since the reef ecosystems of the NWHI may not have encountered such conditions for hundreds, thousands or even millions of years. Table 9.4 presents long-term oceanographic monitoring methods and equipment used in the NWHI since 1999.

The NWHI cover such a large geographical area that the entire archipelago is not exposed to the same oceanographic and meteorological conditions. As an example, Figure 9.24 illustrates the variability in wind strength and direction between French Frigate Shoals in the southern portion of the NWHI and Kure Atoll in the northern portion of the NWHI. At French Frigate Shoals, trade winds from the northeast quadrant clearly dominate the wind field, whereas at Kure Atoll, winds are much more variable with clear signatures of easterly trade winds and westerly winds associated with the passage of low pressure systems. Firing and Brainard (2006) also reported significant variability in surface ocean currents across the archipelago.

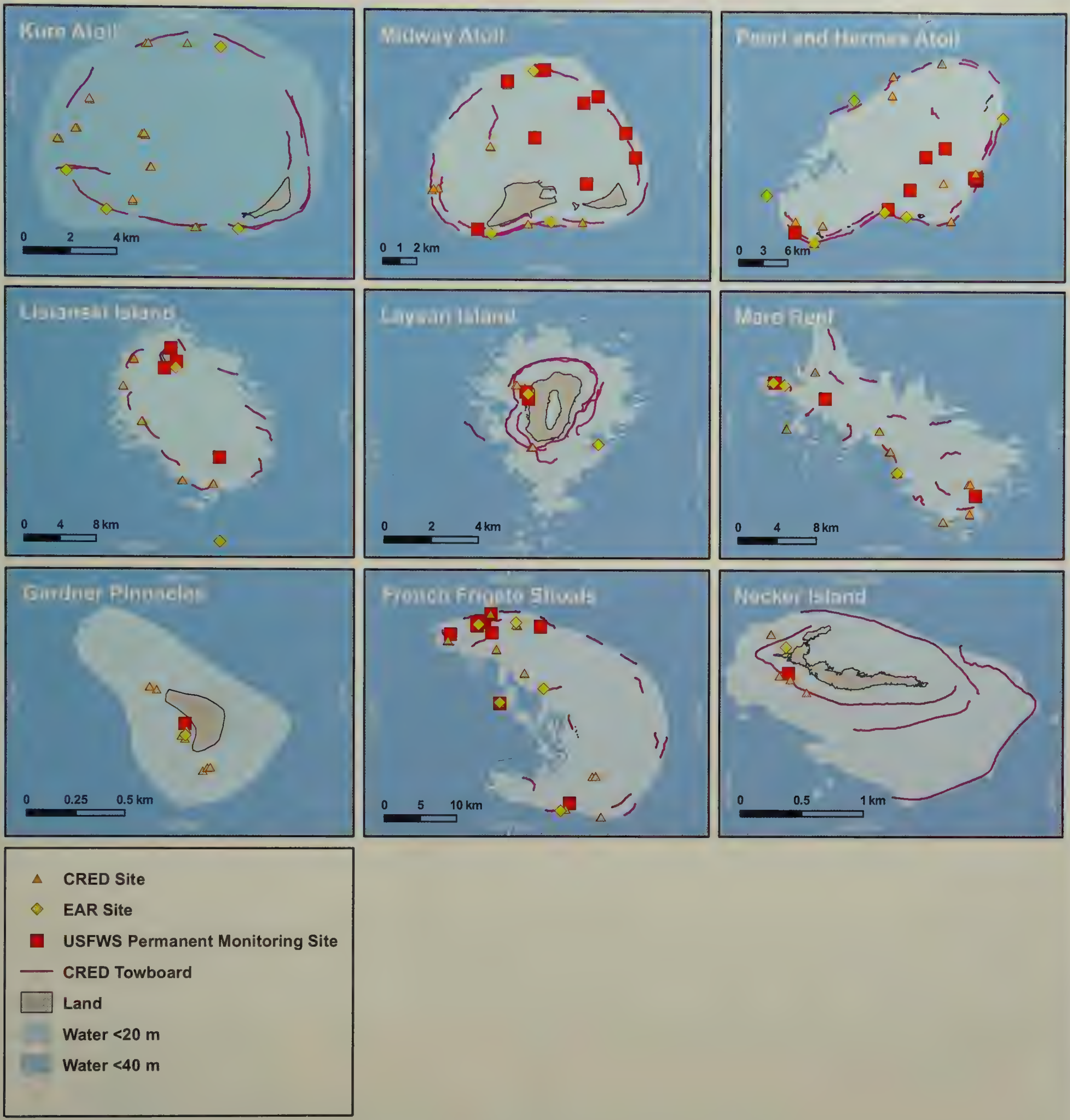

Kure Atoll
0 2 4 km
Midway Atoll
0 1 2 km
Pearl and Hermes Atoll
0 3 6 km
Lisianski Island
0 4 8 km
Laysan Island
0 2 4 km
Maro Reef
0 4 8 km
Gardner Pinnacles
0 0.25 0.5 km
French Frigate Shoals
0 5 10 km
Necker Island
0 0.5 1 km
CRED Site
EAR Site
USFWS Permanent Monitoring Site
CRED Towboard
Land
Water <20 m
Water <40 m

*Figure 9.23. Monitoring locations in the NWHI. Map: K. Buja.*

The NWHI are exposed to large seasonal temperature fluctuations, especially in the northern portions of the archipelago. Temperatures in the summer months across most of the archipelago are typically warm due to high insolation, and ocean waters are generally well-mixed in the upper 30 m of the water column due to steady trade winds and well-stratified below the mixed layer (Figure 9.25). In the winter, the northern portions of the archipelago experience much cooler SSTs relative to the rest of the NWHI as the subtropical front migrates southward and produces vigorous mixing of surface waters due to the combined effects of winds associated with low pressure storm systems and surface cooling associated with cooler air temperatures (Figure 9.25).

Table 9.4. Oceanographic monitoring systems in the NWHI by PIFSC-CRED. Source: PIFSC-CRED.

| SYSTEM | VARIABLES MONITORED | DATES | AGENCY |
|---|---|---|---|
| Deepwater CTDs*<br>at select locations near the islands | Conductivity (salinity), temperature, depth, dissolved oxygen and chlorophyll to a depth of 500 m | February 1999-present | PIFSC-CRED |
| Shallow-water CTDs* -<br>multiple sites each island/atoll | Temperature, salinity, turbidity | February 2000-present | PIFSC-CRED |
| Water Samples | chlorophyll and nutrients (nitrate, nitrite, silicate, phosphate) collected concurrently with CTDs at select depths | September 2004-present | PIFSC-CRED |
| Coral Reef Early Warning Buoys -<br>3 Standard (Kure, Maro, Pearl & Hermes),<br>1 Enhanced (French Frigate Shoals) | Standard: temperature (1 m), conductivity (salinity), wind, atmospheric pressure. Enhanced: standard plus: ultraviolet radiation, photosynthetically available radiation | February 2002-present | PIFSC-CRED |
| Sea Surface Temperature (SST) Buoys -<br>5 (Kure, Laysan, Lisianski, Midway, Necker) | Temperature at 0.5 m | February 2002-present | PIFSC-CRED |
| Subsurface Temperature Recorders -<br>43 (all islands) | Temperature at depths between 0.5 m and 30 m | February 2002-present | PIFSC-CRED |
| Ocean Data Platforms (ODP) -<br>3 (Midway, Necker, Pearl & Hermes) | Temperature, conductivity (salinity), spectral waves, current profiles | October 2002-present | PIFSC-CRED |
| Wave and Tide Recorders (WTR) -<br>4 (Kure 2, Lisianski 2) | Wave and tidal heights | July 2003-present | PIFSC-CRED |
| Ecological Acoustic Recorder (EAR) -<br>4 (French Frigate Shoals, Kure, Pearl & Hermes) | Ambient sounds up to 12.5 kHz and vessel generated sounds | September 2006-present | PIFSC-CRED |

*CTD = conductivity, temperature and depth.

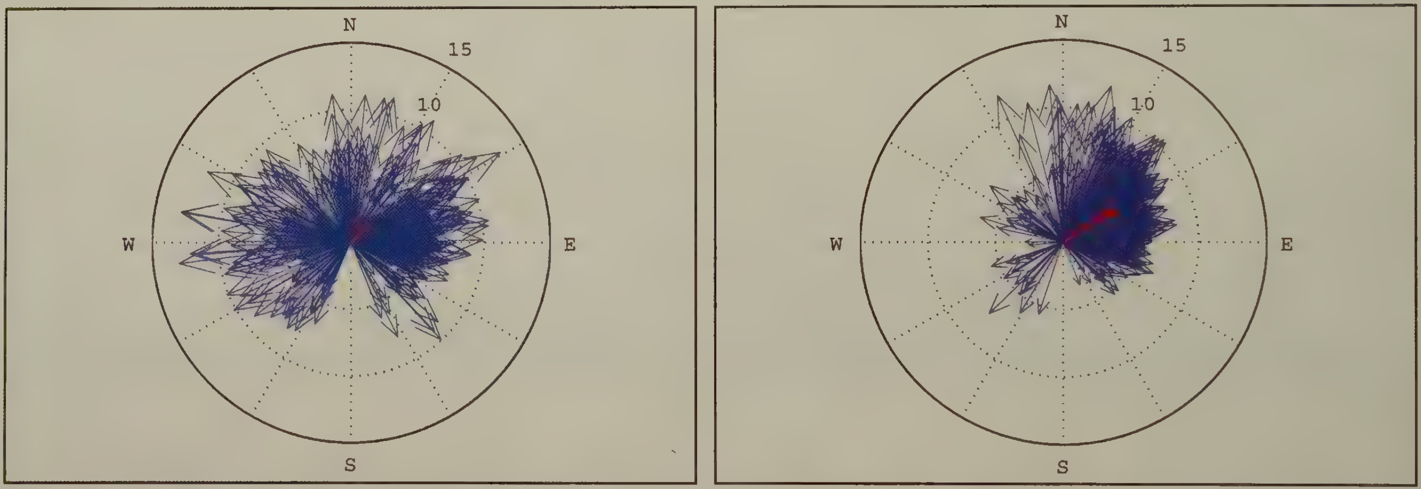


Figure 9.24. Coral Reef Early Warning System buoy data for surface (2 m) wind observations at Kure Atoll (left) from October 5, 2004 to January 13, 2006 and French Frigate Shoals (right) from April 11, 2005 to September 4, 2006. Blue arrows are daily averaged wind direction and speed (from 0-15 m/s) and red arrows are average for the entire period, depicting the prevailing north-northeasterly winds. Wind vectors point to the direction of wind origin. Data points more than 3 SD were excluded. Source: PIFSC-CRED, unpubl. data..

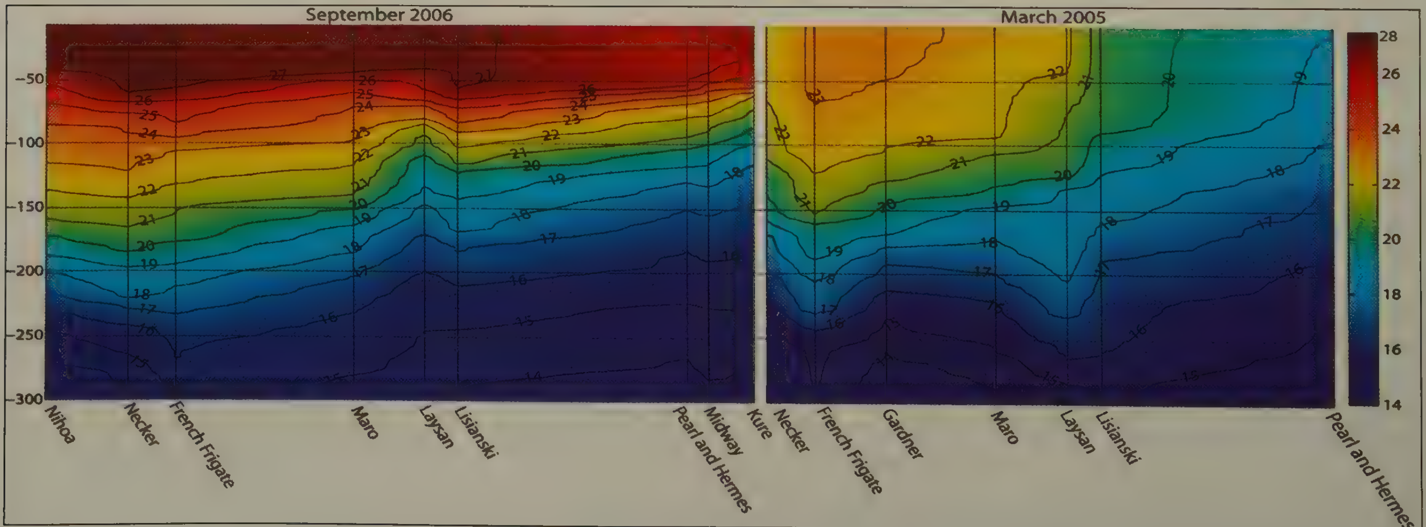


Figure 9.25. Vertical temperature profiles along the NWHI obtained from shipboard conductivity, temperature and depth (CTD) casts during September 2006 (left panel) representing late summer conditions and March 2005 (right panel) conditions representing winter. Depths (y-axis) are in meters and temperature color bar is in °C. Source: PIFSC-CRED, unpub. data.

## BENTHIC HABITATS

### Corals

#### *Range Extensions and Possible New Coral Species*

Recent scientific expeditions in the NWHI have yielded many new records and possibly undescribed species of stony coral since the last compilation by Maragos et al. (2004). One of the most exciting discoveries was of the table coral (*Acropora* spp.) off the spur-and-groove habitat on the southwest side of Pearl and Hermes Atoll and off the shallow southeast fore reef at Neva Shoal. Additional dives confirmed the presence of *Acropora cytherea* and *A. cerealis-valida* at Pearl and Hermes, and *A. valida* at Neva Shoal, which led to other discoveries at Neva, a second *Acropora* species and three *Montipora* species that are all likely new to science.

The Census of Marine Life (CoML) cruise to French Frigate Shoals in October 2006, added additional sightings of rare species including *Diaseris distorta*, *Cycloseris tenuis*, *Leptastrea scabra*, and *Acropora* sp.1. Another rare species, resembling *Leptoseris papyracea,* was previously known only from dredge hauls by Maragos in the MHI, and was reported for the first time in the NWHI off the south east fore reef of French Frigate Shoals during the CoML cruise. An unidentified species, *Porites* sp.15, was reported on a pinnacle on the southwest side of French Frigate Shoals, and the first record of *Porites lutea* in the NWHI was reported from the north reef crest. Other unidentified species reported during the CoML cruise include those pictured in Figures 9.26 and 9.27. The combined 2006 investigations yielded up to 11 new records for the NWHI. Scientists conducting towed-diver surveys contributed directly or indirectly to several of the new records and species, with exploratory dives in new habitats and at new sites contributing the rest (Table 9.5).

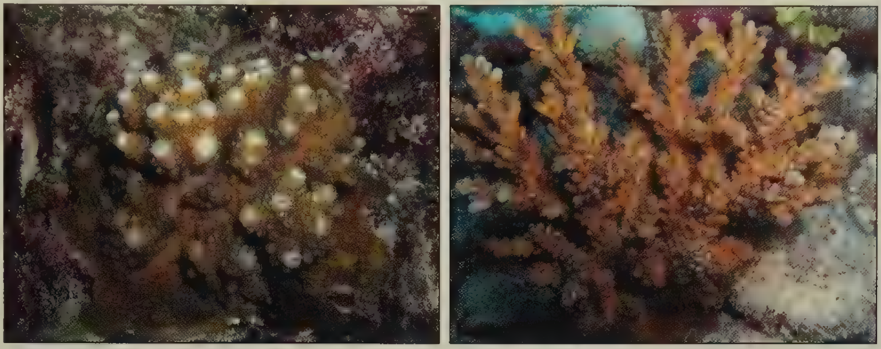


*Figure 9.26. Two potential new species of* Acropora *including the colony on the left and a possible* cf *austera hybrid form (right) from French Frigate Shoals from the* CoML *cruise in October 2006 (right). Photos: J. Maragos.*

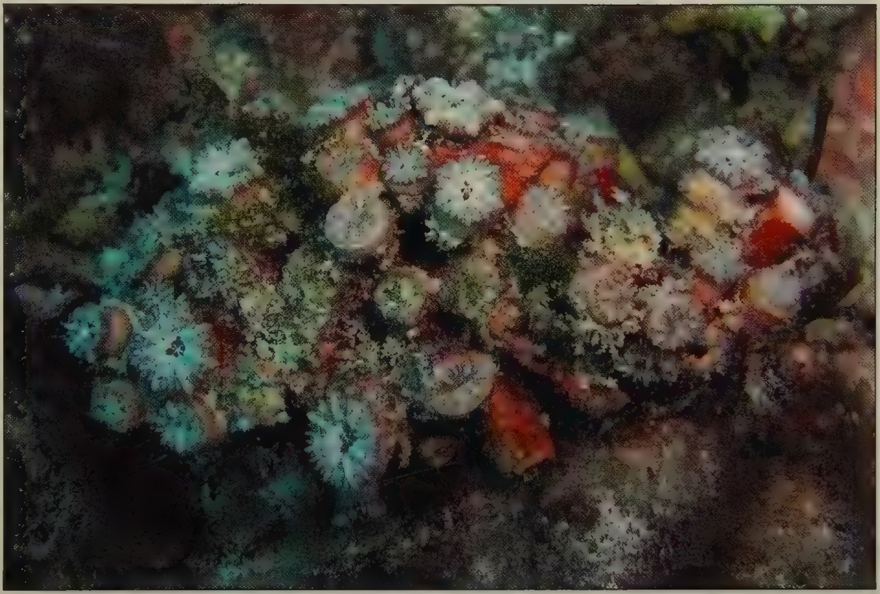


*Figure 9.27. Unidentified new species of coral from French Frigate Shoals. Photo: J. Maragos.*

The most exciting coral discovery was of an unknown species that has not yet been identified to the genus or family level (Figure 9.27). This coral may be a relic that was once common in the past that subsequently died out elsewhere but survived in Hawaii. The other possibility is that the coral may be a type previously restricted to deep water that subsequently evolved and adapted itself to shallow water habitats. Randall (2007) makes note of two fishes that he characterized as relics. Likewise, it may also be possible for relict corals to have survived in Hawaii to this day. It will be necessary to collect this and other corals in order to determine their likely phylogenetic origin. So far there has been no consensus among coral experts looking at the photographs of the coral as to which family it belongs. Marine life in the NWHI evolved for many millions of years in isolation from neighboring archipelagos and islands, and it is plausible that this and perhaps other species were able to survive and thrive without the threat of newer species displacing them as likely occurred in other archipelagos.

The choice of French Frigate Shoals as the target for the first CoML was an excellent one from the standpoint of yielding probable new species and extending the range of many other species. Eight more species of cnidarians were reported from the atoll, further cementing the atoll's status as the most diverse island or atoll for corals in Hawaii. The atoll is the closest site within the Hawaiian chain to Johnston Atoll, which lies 830 km to the southwest, and Johnston may serve as a "stepping stone" for the dispersal of species to Hawaii from the Line Islands and other neighboring archipelagos south of Hawaii (Grigg, 1981; Maragos and Jokiel, 1986; Maragos et al., 2004; Kobayashi, 2006). This connection would explain why French Frigate Shoals has so many *Acropora* species which flourish at Johnston and why French Frigate Shoals has higher numbers of coral species compared to any of the other Hawaiian Islands.

*Table 9.5. A listing of all coral and anemone species reported in the NWHI as of October 2006. Larger atolls with diverse habitats and shelter from large northwestern swells support the greatest number of species. Additional dives to 30 m should fill the void of deeper water species records and yield a more informed assessment of coral and anemone biodiversity. Source: J. Maragos, unpub. data.*

| ISLAND | NIH | NEC | FFS | GAR | MAR | LAY | LIS | PHR | MID | KUR | RAI | NO. OF ISLANDS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Stony Corals** *(*)=undescribed or undetermined species and new records reported from the CoML cruise; cf=unknown, but similar to.* | | | | | | | | | | | | |
| *coral unid., seen first by J. Starmer, sp.18 | | | x | | | | | | | | | 1 |
| *Acropora cerealis* | | | x | x | x | | | | | | | 3 |
| *A. cytherea* | | x | x | x | x | x | | x | | | | 6 |
| *A. gemmifera* | | | x | x | | | | | | | | 2 |
| *A. humilis* | | | x | x | x | | | | | | | 3 |
| *A. nasuta* | | | x | | x | x | | | | | | 3 |
| *A. paniculata* | | | x | | | | | | | | | 1 |
| *A. sp.1 (prostrate) | | | x | | | | x | | | | | 2 |
| *A. sp.28 cf. *retusa* | | | x | | | | | | | | | 1 |
| *A. valida* | | | x | | x | x | x | x | | | | 5 |
| *A. sp.29 (table) | | | x | | | | | | | | | 1 |
| *A. sp.30 cf. *palmerae* | | | x | | | | | | | | | 1 |
| A. sp. 20 (neoplasia/tumor?) | | | x | | | | | | | | | 1 |
| A. sp.26 cf. *loripes* | | | x | | | | | | | | | 1 |
| *Montipora capitata* | x | x | x | x | x | x | x | x | x | x | x | 11 |
| *M. flabellata* | | x | x | x | x | x | x | x | x | x | | 9 |
| *M. patula* | x | x | x | x | x | x | x | x | x | x | | 10 |
| *M. sp.4 cf. incrassata | | x | x | | x | | | | | x | | 4 |
| M. dilatata | | | | | | x | x | | | | | 2 |
| *M. sp.6 cf. dilatata | | | | | x | | | | | | | 1 |
| *M. sp.7 (foliaceous) | | | x | | | | x | x | x | | | 3 |
| *M. sp.2 (ridges) | | | | | | | | x | | x | | 2 |
| *M. sp.5 (branching) | | | | | | | | | | | | 1 |
| *M. sp.14 (nodular) first seen by *B. Vargas-Angel* | | | | | | | | x | | | | 1 |
| *M. tuberculosa* | | | x | | x | x | x | x | x | x | | 7 |
| *M. sp.24 (irregular) | | | x | | | | | | | | | 1 |
| *M. sp.3 cf. *turgescens* | | | | | x | x | x | x | x | x | | 6 |
| *M. verrilli* | | | x | | x | x | x | x | x | x | | 7 |
| *Gardineroseris planulata* | | | | | | | | | x | | | 1 |
| *Leptoseris hawaiiensis* | | | x | | | x | | | | | | 1 |
| *L. incrustans* | | | x | | | | | x | x | x | | 4 |
| *L. sp.22 cf. *incrustans* | | | x | | | | | | | | | 1 |
| *L. mycetoseroides* | | | x | | | | | | | | | 1 |
| *L. cf. *papyracea* sp19 | | | x | | | | | | | | | 1 |
| *L. cf. *scabra* sp17 | | | x | | | | x | | | | | 2 |
| *Pavona clavus* | | | | | | | | x | x | x | | 3 |
| *P. duerdeni* | x | x | x | x | x | x | x | x | x | x | | 10 |
| *P.maldivensis* | | | x | | x | | x | x | x | x | | 6 |
| *P. varians* | x | x | x | x | x | x | x | x | x | x | | 10 |
| **Balanophyllia sp.* (pink) | | | x | | x | | | | | x | | 3 |
| *Cladopsammia eguchii* | | | x | x | x | x | | x | x | x | | 7 |
| *Tubastraea coccinea* | x | | x | x | x | x | | x | x | x | x | 9 |
| *Cyphastrea ocellina* | x | x | x | x | x | x | x | x | x | x | | 10 |
| *Leptastrea agassizi* | | | x | | x | | | | x | | | 3 |
| *L. bewickensis* | | | x | | | | x | x | | | | 3 |
| *L. purpurea* | x | x | x | x | x | x | | x | x | x | | 10 |

| ISLAND | NIH | NEC | FFS | GAR | MAR | LAY | LIS | PHR | MID | KUR | RAI | NO. OF ISLANDS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *L. pruinosa* |  | x | x | x | x |  |  |  |  |  |  | 4 |
| *L. sp.8 cf. *F. hawaiiensis* |  | x | x |  | x |  | x |  |  | x |  | 5 |
| **Cycloseris tenuis* |  |  | x | x |  |  | x | x |  |  |  | 3 |
| **C. vaughani* |  |  | x |  |  |  | x | x | x |  |  | 3 |
| *Diaseris distorta* |  |  | x |  |  |  | x |  |  |  |  | 2 |
| *Fungia scutaria* | x |  | x | x | x | x | x | x | x | x |  | 9 |
| *F. granulosa* |  |  |  |  | x | x |  | x |  |  |  | 3 |
| *Pocillopora damicornis* |  |  | x |  | x | x | x | x | x | x | x | 8 |
| *P. eydouxi* | x | x | x | x | x | x | x | x | x |  |  | 9 |
| P. sp.10 cf. *laysanensis* |  |  | x |  |  | x |  |  |  | x | x | 4 |
| *P. ligulata* | x | x | x | x | x | x | x | x | x | x | x | 11 |
| *P. meandrina* | x | x | x | x | x | x | x | x | x | x |  | 10 |
| *P. molokensis* | x |  | x | x | x | x | x | x |  | x | x | 9 |
| P. sp.32 cf. *verrucosa* |  |  | x |  |  |  | x | x |  |  |  | 3 |
| P. sp.33 cf. zelli |  |  | x |  |  |  |  |  |  |  |  | 1 |
| *P. sp.11 cf. capitata |  |  | x |  | x | x | x | x | x | x | x | 8 |
| **Porites* sp.12 cf. annae |  |  |  |  |  |  | x | x |  | x |  | 3 |
| *P. sp. 15 (paliform lobes) |  |  | x |  |  |  |  |  |  |  |  | 1 |
| *Porites brighami* | x | x | x | x | x | x | x | x |  | x |  | 9 |
| *P. compressa* | x | x | x | x | x | x | x | x | x | x | x | 11 |
| *P. sp.23 (arthritic fingers) |  |  | x |  |  |  |  |  |  |  |  | 1 |
| *P. duerdeni* |  | x | x | x | x |  |  | x |  | x |  | 6 |
| *P. evermanni* | x | x | x | x | x | x | x | x | x | x |  | 10 |
| *P. hawaiiensis* |  | x | x |  | x | x | x | x | x | x |  | 9 |
| *P. lobata* | x | x | x | x | x | x | x | x | x | x |  | 10 |
| *P. sp. 21 cf. *lobata* |  |  | x |  |  |  |  |  |  |  |  | 1 |
| **P. sp.16 cf. lutea* |  |  | x |  |  |  |  |  |  |  |  | 1 |
| *P. rus* |  |  |  |  | x |  |  |  |  |  |  | 1 |
| *P. sp.27 (columns) |  |  | x |  |  |  |  |  |  |  |  | 1 |
| *P. sp.13 cf. *solida* |  |  | x | x |  | x |  | x | x | x |  | 5 |
| *Psammocora explanulata* |  |  |  | x |  |  |  |  |  |  |  | 1 |
| *P. nierstraszi* |  | x | x | x | x | x | x | x | x |  |  | 8 |
| *P. stellata* | x |  | x | x | x | x | x | x | x | x | x | 10 |
| *P. verrilli* |  |  |  |  |  |  |  | x | x | x |  | 3 |
| **NON-STONY CORALS & ANEMONES** *(*)=undescribed or undetermined species and new records reported during the CoML cruise.* |  |  |  |  |  |  |  |  |  |  |  |  |
| *Palythoa tuberculosa* | x | x | x | x | x | x | x | x | x | x |  | 10 |
| *P. sp.* |  |  | x |  |  |  |  |  |  |  |  | 1 |
| *Zoanthus pacificus* |  |  | x |  | x |  |  | x |  | x |  | 4 |
| *Zoanthus* sp (Kure) |  |  |  |  |  |  |  |  |  | x |  | 1 |
| *Zoanthus* sp ("B") | x | x | x |  | x |  | x |  |  |  |  | 5 |
| **Sinularia* sp (yellow) | x | x | x | x |  |  | x |  |  |  |  | 5 |
| **Sinularia* (purple) |  |  |  | x |  |  |  |  |  | x |  | 2 |
| **Sinularia* (brown) |  |  | x |  |  |  |  |  |  |  |  | 1 |
| **Sinularia* (pink) |  |  |  |  |  |  |  | x |  |  |  | 1 |
| *Acabaria* bicolor |  |  | x |  |  |  |  |  |  | x |  | 2 |
| *Cirrhipathes* sp | x |  | x |  |  |  |  |  |  |  |  | 1 |
| *Heteractis malu* |  |  | x | x | x | x |  |  |  | x |  | 5 |
| **TOTAL SPECIES PER ISLAND** | **21** | **24** | **75** | **33** | **44** | **35** | **41** | **46** | **34** | **42** | **9** |  |
| **Total Species of Stony Corals: 80** |  |  |  |  |  |  |  |  |  |  |  |  |
| **Total For All Cnidarians: 89** |  |  |  |  |  |  |  |  |  |  |  |  |

## Assessment and Monitoring Sites

In 2003, 73 REA sites were chosen as long-term monitoring sites from more than 500 sites assessed during NWHI RAMP surveys between 2000 and 2002. The sites were selected to represent a diversity of habitats at each island/atoll within constraints imposed by prevailing weather conditions and shipboard operational logistics. At each site, REA coral survey protocols built upon quantitative methods that were initiated in 2002 to compute several parameters that collectively describe community structure: coral percent cover, richness, relative abundance, colony density and size-frequency distribution. Surveys were conducted along two 25 m transects at each site, and included video records of benthic substrate and condition. The line-intercept method at 0.5 m intervals was introduced as a standard part of the survey protocol in 2004 to more efficiently quantify substrate composition (Figure 9.28). Directed observations on coral disease, predation and bleaching were conducted along the same transect lines. Surveys using the same methods were conducted in 2004, 2005 and 2006, with only minor modifications to the suite of sites chosen for long-term monitoring. Not all sites were surveyed in all years, due to factors including sea conditions and available ship time.

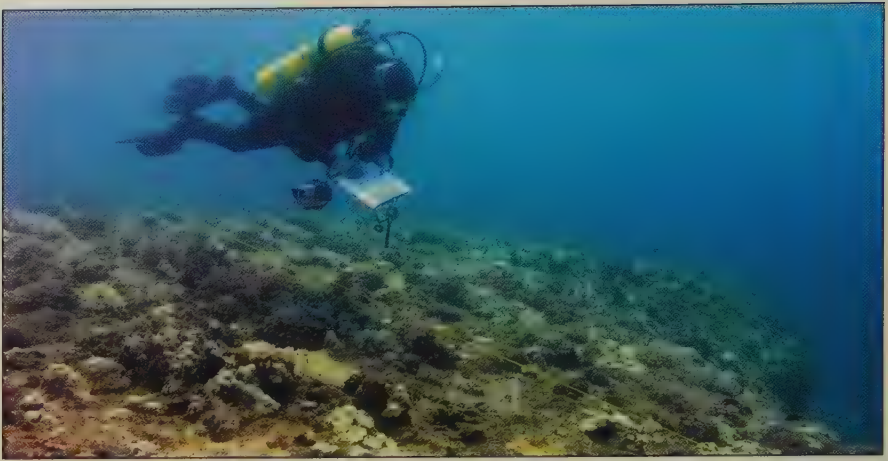


Figure 9.28. A diver uses the line-intercept method to document benthic composition at 0.5 m intervals along transects. Photo: J. Kenyon.

Coral distribution, abundance, and condition were assessed on larger spatial scales using towed–diver surveys (Kenyon et al., 2006b). As field efforts in 2003 transitioned from reef assessment to reef monitoring, specific track lines were chosen as targets for resurveys in 2003, 2004 and 2006.

## Coral Percent Cover and Relative Abundance from REAs

Coral REA surveys were conducted at 70 sites in 2004, 37 sites in 2005 and 64 sites in 2006 (Table 9.6). As with percent cover data from 2002 surveys (which were calculated from size frequency data of colony counts within transects), line-intercept data from surveys during all three years indicated that coral cover varied greatly across the NWHI (Figure 9.29). Most locations had low coral cover (<20%), with higher values at Maro, Lisianski and French Frigate Shoals. Coral cover values determined from 2002 surveys also showed the highest coral cover values at Maro and Lisianski (Friedlander et al., 2005), though their magnitude (more than 60%) was greater than the values derived from the line-intercept method in 2004-2006. At each island/atoll, mean coral cover values from different survey years (2004, 2005 and 2006) were similar, indicating relatively little change overall at each location.

Relative abundance of cnidarians was assessed by computing the proportion of colonies, by taxon, that occurred within belt transects (Table 9.7). These data, from 2006 surveys, exemplify some general patterns seen during all years. The relative abundance of corals varied among locations, though *Porites lobata* composed a majority of the fauna at numerous locations and was an important component of the fauna at all locations. *Acropora*, particularly *A. cytherea*, was an important component of the coral fauna at French Frigate Shoals, but less so at other locations where it occurred (Necker

Table 9.6. Number of REA and towed-diver surveys (TDS) conducted by PIFSC-CRED (2004 and 2006) and PMNM (2005). Source: PIFSC-CRED, unpubl. data.

| ISLAND | 2004 | | 2005 | | 2006 | |
|---|---|---|---|---|---|---|
| | REA | TDS | REA | TDS | REA | TDS |
| Necker | 3 | 0 | 3 | 0 | 2 | 4 |
| FFS | 11 | 17 | 6 | 0 | 10 | 19 |
| Gardner | 3 | 2 | 0 | 0 | 0 | 0 |
| Maro | 9 | 12 | 7 | 0 | 9 | 13 |
| Laysan | 3 | 5 | 0 | 0 | 3 | 6 |
| Lisianski | 9 | 12 | 0 | 0 | 9 | 12 |
| PHR | 14 | 21 | 9 | 0 | 13 | 26 |
| Midway | 9 | 15 | 6 | 0 | 9 | 15 |
| Kure | 9 | 13 | 6 | 0 | 9 | 13 |

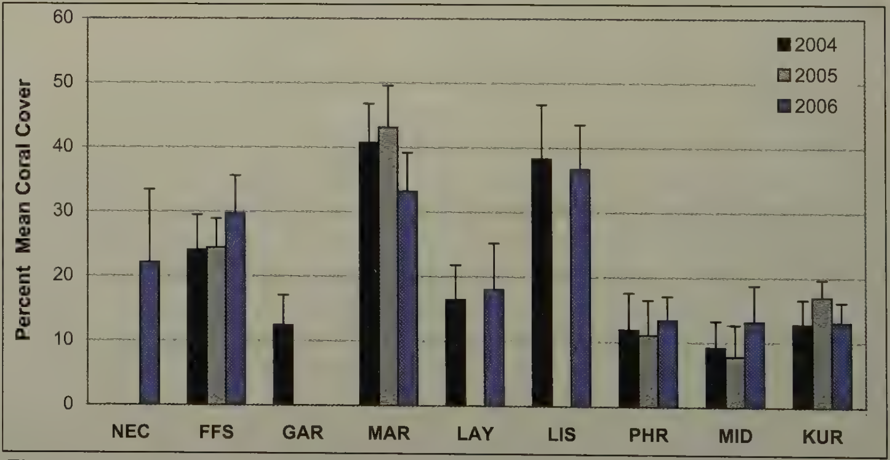


Figure 9.29. Mean coral cover (±SE) at locations in the NWHI. Not all locations were surveyed in all three years. Coral cover was calculated from the line-intercept method at 0.5 m intervals. Source: PIFSC-CRED, unpub. data.

*Table 9.7. Relative abundance of cnidarian colonies in the NWHI based on REA surveys at 64 sites conducted by PIFSC-CRED in 2006. All cnidarian species for which at least one colony was tallied in at least one location are listed. Those contributing >10% of the coral fauna at each location are highlighted in bold. Source: PIFSC-CRED.*

| SPECIES | PERCENT OF CNIDARIAN FAUNA | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | NECKER | FFS | MARO | LAYSAN | LISIANSKI | PHR | MIDWAY | KURE |
| *Acropora cytherea* | 0.0% | **10.7%** | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% |
| *Acropora valida* | 0.0% | 5.1% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% |
| *Acropora humilis* | 0.0% | 0.3% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% |
| *Montipora capitata* | 2.8% | 2.6% | **15.1%** | 9.4% | **17.7%** | 6.3% | 1.1% | 2.7% |
| *Montipora patula* | 2.5% | 2.5% | 5.2% | 1.6% | 6.8% | 1.0% | 0.1% | 0.0% |
| *Montipora flabellata* | 0.0% | 0.0% | 0.7% | 0.0% | 0.0% | 0.5% | **13.6%** | 1.9% |
| *Montipora incrassata* | 0.3% | 0.1% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% |
| *Pavona duerdeni* | 1.9% | 2.5% | 2.5% | 3.8% | 2.1% | 0.3% | 0.0% | 0.0% |
| *Pavona varians* | 0.1% | 0.0% | 0.0% | 2.1% | 0.1% | 0.3% | 0.4% | 0.2% |
| *Pavona maldivensis* | 0.0% | 0.0% | 0.0% | 0.0% | 1.1% | 0.2% | 0.0% | 0.0% |
| *Cyphastrea ocellina* | 0.0% | 7.6% | 4.8% | 4.5% | **18.8%** | 1.5% | 0.9% | 1.5% |
| *Leptastrea purpurea* | 0.6% | 1.0% | 0.2% | 0.2% | 0.3% | 7.3% | 1.1% | 3.6% |
| *Fungia scutaria* | 0.0% | 0.0% | 0.5% | 0.0% | 0.9% | 2.4% | 0.0% | 0.0% |
| *Leptoseris incrustans* | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.1% | 0.0% |
| *Pocillopora damicornis* | 0.0% | 6.9% | 0.7% | 0.0% | 6.4% | 2.6% | 8.5% | **13.4%** |
| *Pocillopora eydouxi* | 0.0% | 0.1% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% |
| *Pocillopora ligulata* | 0.7% | 0.4% | 1.2% | 0.0% | 0.6% | 0.1% | 0.2% | 0.5% |
| *Pocillopora meandrina* | **28.9%** | 8.1% | 6.5% | **17.4%** | 1.1% | **26.2%** | **11.3%** | **52.4%** |
| *Porites brighami* | 0.6% | 1.1% | 0.3% | 3.8% | 0.6% | 0.0% | 0.0% | 0.0% |
| *Porites compressa* | 3.8% | **15.9%** | **39.8%** | 1.9% | 9.7% | 8.5% | 6.3% | 5.4% |
| *Porites evermanni** | 2.0% | 1.5% | 1.3% | 0.2% | **11.9%** | 0.0% | 0.1% | 0.1% |
| *Porites lobata* | **55.3%** | **32.2%** | **20.1%** | **54.9%** | **20.6%** | **37.1%** | **55.9%** | **16.3%** |
| *Psammocora nierstraszi* | 0.0% | 0.1% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% |
| *Psammocora stellata* | 0.0% | 0.1% | 0.0% | 0.2% | 1.3% | 3.3% | 0.2% | 1.1% |
| *Palythoa sp.* | 0.6% | 1.3% | 1.0% | 0.0% | 0.0% | 2.3% | 0.1% | 0.8% |
| **Total cnidarians counted** | 689 | 2,408 | 2,443 | 426 | 1,920 | 2,319 | 1,158 | 1,929 |
| **Area surveyed (m²)** | 100 | 500 | 450 | 100 | 450 | 650 | 425 | 450 |

* **Note:** *Porites evermanni* is considered to be *P. lutea* by *Fenner 2005*.

to Pearl and Hermes, inclusive). *Pocillopora meandrina* and *Montipora capitata* were both abundant at some locations but less common at others. Numerous taxa were represented throughout the NWHI at very low levels of abundance; although 57 species of stony corals have been documented in the NWHI (Maragos et al., 2004), many species occur at such low frequencies that they were not encountered within survey transect belts. Thus, relatively few coral species numerically dominate throughout the NWHI. When species are pooled by genus, *Porites*, *Pocillopora*, and *Montipora* collectively emerged as the numerically dominant genera throughout the NWHI though their relative abundance varied by location (Figure 9.30).

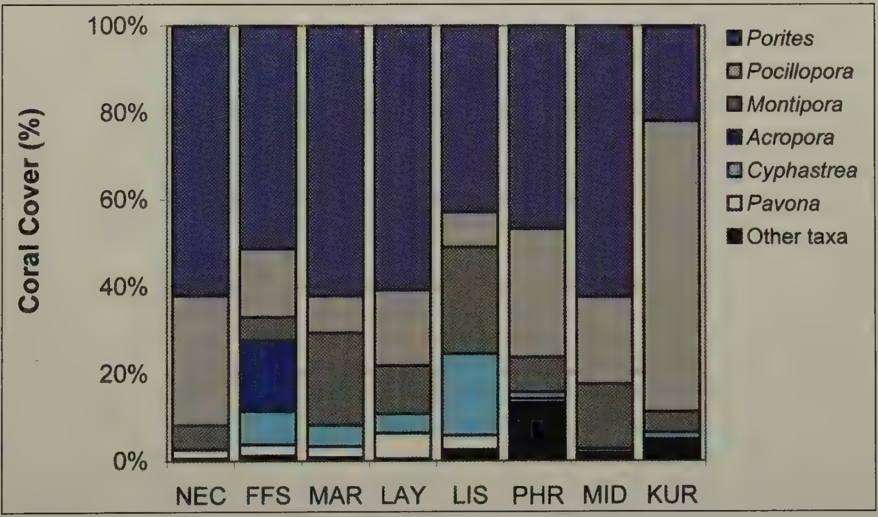


*Figure 9.30. Relative abundance of coral genera in the NWHI. Data are derived from colony counts within belt transects during 2006 surveys. Source: PIFSC-CRED.*

Coral colony size-frequency distributions can reveal important characteristics of reef communities, and can be used as a tool to estimate the response of coral populations to the environment. The size-frequency distributions of all cnidarians enumerated in belt transects throughout the NWHI in 2003, 2004 and 2006 indicate generally similar distributions in all three survey years, which in turn suggests stability in the complexity of the structural framework that provides shelter to numerous species of reef inhabitants.

## *Monitoring Corals at Permanent Transect Sites in the Northwestern Hawaiian Islands 2001-2006*

This section focuses on the results of monitoring coral communities at 27 permanently marked transects established at seven NWHI reefs from 2001-2002 and resurveyed in September 2006. Friedlander et al., (2005) provides background information on the procedures used to establish permanent transects and the status of the communities at all 42 permanent transects from 2000-2002. Fifteen of the sites could not be resurveyed in 2006 due to time and logistical constraints.

### Methods

Data collected during the surveys were used to compute the number of coral genera per transect, coral densities (number per m$^2$), mean diameter (cm), percent coral cover and size/population frequency distribution of corals and anemones reported on transects. The original surveys relied on post-hoc analysis of quadrat photos that had been scanned into a computer, however, surveys at the sites in 2006 relied on *in situ* censuses of corals, initially following the protocols described in Maragos et al. (2004) with subsequent modifications. Corals were censused within a meter-wide belt along the transect lines at all 27 permanent transects in 2006. Each coral whose center fell within one-half meter of either side of the transect line was assigned to a genus and one of seven size classes (1-5 cm, 6-10 cm, 11-20 cm, 21-40 cm, 41-80 cm, 81-160 cm and >160 cm) based upon the visually estimated length of each colony's longest diameter. Notes and digital photographs were also collected on and off transect to gain information on coral species diversity, disease, predation, etc.

Calculated estimates of coral cover at both REA and permanent transect sites using length-to-area conversions of size class data was proposed by Maragos et al. (2004). Percent coral cover data collected at 48 transects in the NWHI in 2000-2002 were used to calibrate an accurate length-to-area conversion based on measurements (to the nearest cm) of the colony's longest diameter collected from the same scanned photos. As with the *in situ* surveys, each coral in the quadrat photos was assigned to one of the seven classes and evaluated against the estimates using smaller length-to-area conversions. The calibrations resulted in the development of correction factors for length-to-area conversions by size class. These corrections and conversions are summarized in Table 9.8 and were applied to all permanent transect data from 2000-2006 to insure the consistency afforded by the use of a single technique. Figure 9.31 is a scatter diagram of the conversions in relation to the scanned estimates of percent coral cover.

*Table 9.8. Size classes, mean diameter, and length-to-area conversions used for all coral NWHI permanent transects. The conversions are also used in the Pacific Remote Island Areas and Rose Atoll coral sections of this report. Source: J. Maragos.*

| SIZE CLASS | MEAN DIAMETER | AREA FORMULA | | AREA/ CORAL |
|---|---|---|---|---|
| | $D=(n^{max} + n^{min})/2$ | $A= (\pi r^2)/2$ | $A'=(A^{max}+ A^{min})/2$[1] | |
| 1-5 cm | 3 cm | (1.5x1.5x3.14)/2 | N/A | 3.55 cm$^2$ |
| 6-10 cm | 8 cm | (4x4x3.14)/2 | N/A | 25.1 cm$^2$ |
| 11-20 cm | 15.5 cm | (7.75x7.75x3.14)/2 | N/A | 88.5 cm$^2$ |
| 21-40 cm | 30.5 cm | (15x15x3.14)/2 | N/A | 353 cm$^2$ |
| 41-80m | 60.5 cm | (30x30x3.14)/2 | N/A | 1,413 cm$^2$ |
| 81-160 cm | 120.5 cm | (60x60x3.14)/2 | (5,652+1,413)/2 | 3,532 cm$^2$ |
| >160 cm | 180 cm | (120x120x3.14)/2 | (10,000+10,000)/2 | 10,000 cm$^2$ |

[1] Applies only to two largest size classes.

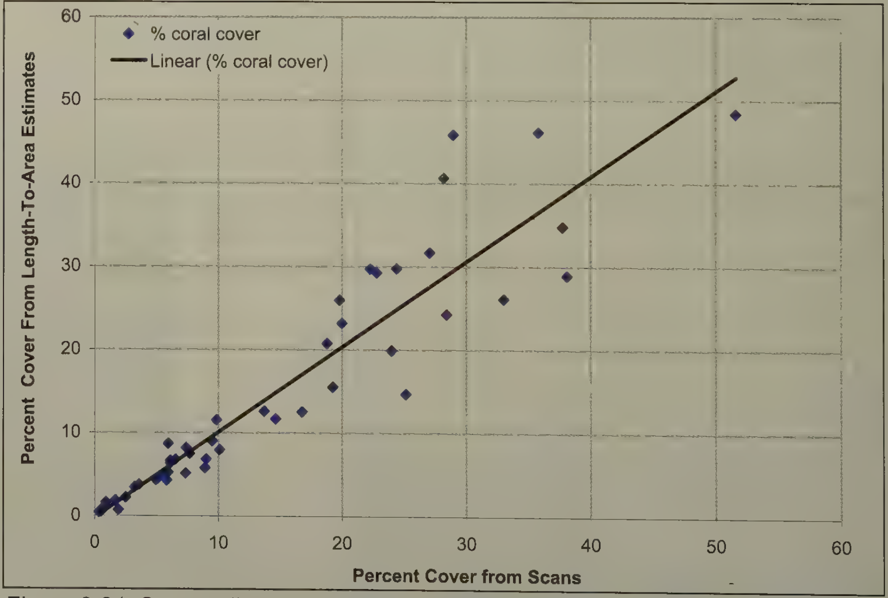


*Figure 9.31. Scatter diagram of percent coral cover per site estimated from the sum of all coral areas inside all 2000-2002 NWHI photoquadrats using Sigma Scan™ software (x-axis), compared to estimates based upon assigning all scanned coral long diameters to the appropriate size classes and using the sum of length-to-area conversions in Table 9.9 to calculate percent cover for corals whose centers fell inside the quadrat frame (y-axis). N=48 transects, 1,937 m$^2$ and 9,264 corals. Source: Maragos, 2007.*

### Results and Discussion

Changes in percent coral cover, mean diameter, number of coral genera and the density of all corals per transect were compared between 2001-2002 and 2006 at permanent transects (Table 9.9; Figure 9.32). Mean coral cover declined by 2% from 2001-2002 to 2006 but was not significantly different (W=53, p=0.51). The mean colony diameter declined significantly (-15%) from 2001-2002 to 2006, while the mean number of coral genera (+46%) and density (+58%) both increased significantly over that same time period (W=236, p=0.004; t=2.26, p=0.03, respectively). Changes in the survey techniques between the two sets of surveys explain some of these patterns. For one, comparison of *in situ* census of corals in 2006 with analysis of photos would likely lead to the detection of more small coral genera, leading to lower mean diameter values. However, the analysis of the individual sites over time reveals that some of these trends can only be explained by changes in the coral populations.

*Table 9.9. Percent coral cover, mean diameter, number of genera and frequency of all corals at each of 27 permanent transect sites surveyed in 2001-2002 and 2006. Bold numbers are the higher of two (earlier or later) values at each site. The asterisk (*) indicates that 2006 data not available at this site and the most current data collected in 2002 are instead provided. Source: Maragos, 2007.*

| SITE NUMBER | HABITAT | LOCALE | DATE | PERCENT CORAL COVER | | MEAN DIAMETER CM | | NUMBER GENERA/SITE | | DENSITY (#/m²) | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 2001-2002 | 2006 | 2001-2002 | 2006 | 2001-2002 | 2006 | 2001-2002 | 2006 |
| FFS- 5P | fore reef | NW | 7/17/2001 | **19.4** | 16.8 | 11.6 | **13.3** | **4** | 3 | **14.2** | 11.7 |
| FFS 3P | lagoon basalt | N cen. | 7/16/2001 | 27.7 | **28.8** | **19.9** | 17.8 | 5 | 5 | 8.5 | **11.5** |
| FFS 16P | Lagoon | N | 9/15/2001 | 4.8 | **9.5** | 12.3 | **15.1** | **5** | 4 | 4.6 | **7.8** |
| FFS 2P | reef crest | S | 7/15/2001 | 27.2 | **33.5** | **26.2** | 20.1 | **7** | 6 | 5.3 | **9.4** |
| FFS 11P | back reef | N | 10/30/2002 | **39.1** | 22 | **76.2** | 21.3 | 3 | **4** | 1.6 | **5.9** |
| LAY 1P | channel | S | 9/17/2001 | **5.9** | 5.1 | 7.7 | **10.9** | 3 | **6** | **9.5** | 4.9 |
| LAY 5P | reef pool | SE | 9/18/2002 | 7.7 | **8.7** | 11 | **14.6** | 3 | **4** | **5.6** | 4.8 |
| LIS 1P | reef crest | S cen. | 9/30/2002 | **5.3** | 0.43 | **14.5** | 4.6 | 2 | **4** | **3.8** | 0.36 |
| LIS 9P | pinnacle | E | 10/2/2002 | 19.2 | **24.9** | **22.9** | 16.3 | 2 | **4** | 5.1 | **9.8** |
| LIS 6P | fore reef | N | 10/1/2002 | 27.9 | **46.8** | **57.4** | 40.6 | 1 | **3** | 1.8 | **4** |
| MAR 4P | back reef | NW | 9/16/2002 | **52** | 34.4 | **36.4** | 20.6 | 3 | **7** | 6.4 | **11.4** |
| MAR 5P | Lagoon | center | 9/21/2001 | 4.2 | **5.9** | **10.9** | 10.3 | 2 | **5** | 3.8 | **5.1** |
| MAR 1P | fore reef | SE | 9/15/2002 | **32.4** | 7.9 | **29.6** | 9.3 | 3 | **7** | 4.6 | **8.2** |
| MID 7P | Lagoon | E | 9/23/2002 | **50** | 1.1 | **25** | 7.6 | 4 | 4 | nd. | 3.2* |
| MID 16P | back reef | N | 12/3/2002 | 24.3 | **36** | **46.7** | 29.7 | 3 | 3 | 2.1 | **5.8** |
| MID 14P | lagoon pinnacle | center | 9/24/2002 | 4.7 | **12.2** | 8 | **12** | 2 | **3** | **12.2** | 9.5 |
| MID 18P | back reef | NE | 12/4/2002 | 0.7 | **1.3** | 6.8 | **7.4** | 4 | **5** | 2.5 | **3.5** |
| MID 19P | lagoon pinnacle | SW | 12/5/2002 | **5.1** | 0.9 | **14.7** | 13.1 | 2 | **3** | **2.77** | 1.02 |
| MID 20P | back reef | NW | 12/6/2002 | **22.3** | 19.2 | **48.7** | 31 | **3** | 2 | 1.46 | **2.7** |
| MID 1Pa | reef crest | E | 12/3/2002 | **3.3** | 1.04 | **17.6** | 11.7 | 2 | **4** | 1.73 | **2.46** |
| MID 2P | back reef | NE | 9/21/2002 | 13.8 | 13.8 | **22.6** | 21.3 | 4 | 4 | 2.8 | 2.8 |
| MID 17P | back reef | E | 12/4/2002 | **9** | 3.5 | 10.4 | **20** | 2 | **4** | **4.6** | 1 |
| NEC 1P | basalt fore reef | S | 9/9/2002 | 6 | **14.6** | 8.4 | **10.6** | 2 | **4** | 9.1 | **18.4** |
| P&H 6P | lagoon pinnacle | S | 9/19/2002 | **2.53** | 1.53 | **11.7** | 7.6 | 2 | **4** | 1.8 | **4.8** |
| P&H 7P | lagoon patch reef | center | 9/27/2002 | **24** | 20.7 | **25.6** | 10.1 | 1 | **3** | **4.64** | 19.8 |
| P&H 9P | Pass | S | 9/28/2002 | **1.69** | 0.23 | **14.4** | 9.5 | 2 | **4** | **1.07** | 0.4 |
| P&H 12P | fore reef | SW | 9/29/2002 | **8.95** | 7.11 | **15.5** | 11.1 | 3 | **6** | 3.15 | **6.48** |
| **TOTALS** | **27** | | **MEANS** | **16.64** | 14 | **22.69** | 15.46 | 2.9 | **4.3** | 4.8 | **6.7** |

The 27 permanent transects resurveyed in 2006 represent two-thirds of the total established from 2000-2002 and accounts for only a small subset of the coral reef habitat in the NWHI. Consequently, a generalization on the overall status of the archipelago's reefs is not possible. The PIFSC- CRED program established an additional 60 permanent transects in 2006, and the results of the REA surveys are presented in the previous section. More than 100 total permanent transects will continue to be monitored in future years to better assess the status of the reefs within the newly established PMNM.

### Towed-Diver Surveys

More than 200 towed-diver surveys were conducted throughout the NWHI during the period 2004-2006 (Table 9.6). Towed-diver surveys conducted in 2003, 2004 and 2006 replicated specific track lines surveyed in previous years as field efforts shifted from assessment to monitoring (Figure 9.33).

Detailed analysis of imagery recorded during 2003 throughout the NWHI has been completed, using a point-count methodology (Kohler and Gill, 2006) for images recorded at 30-second intervals (about 20 m distance). Percent coral cover estimates derived from these analyses (Figure 9.34) compare favorably with the relative ranking of regions as determined from estimates derived from REA surveys at fixed sites (Figure 9.29). Both methods indicate that Lisianski and Maro had the highest coral cover, with French Frigate Shoals ranking third. However, the magnitude of the estimates derived from the two methods differs, with towed-diver surveys yielding lower percent cover values than REA surveys. This difference is expected since towed-diver surveys assess all habitat types along a survey track, including soft bottom habitats, whereas REA surveys target only hard bottom communities.

At Pearl and Hermes Atoll, where benthic imagery recorded during surveys conducted in 2000 and 2002 has received detailed analysis (Kenyon et al., 2007), three genera – *Porites*, *Montipora* and *Pocillopora* – accounted for 97% of the coral cover throughout the atoll, though their relative abundances varied considerably according to habitat and geographic sector within habitats (Kenyon et al., 2007). Fore reef communities were dominated by massive and encrusting *Porites*, while the back reef was dominated by *Montipora* and the lagoon by *Porites compressa* (Figure 9.35). The relative abundance of dominant coral taxa at Pearl and Hermes differed considerably from coral dominance patterns at French Frigate Shoals (Kenyon et al., 2006c), particularly in back reef and lagoon habitats.

## Algae

Quantitative algal monitoring continued during 2005-2006, with 39 sites visited by the PMNM in 2005 and 67 sites visited by the PIFSC-CRED in 2006. Continued use of the algal monitoring protocol developed in 2002 (Preskitt et al., 2004) assured uniformity of data for statistical temporal analyses. Qualitative assessment of study areas completed in conjunction with quantitative surveys allowed for the discovery of one species of red algae new to science, *Dasya atropurpurea* (Figure 9.36; Vroom, 2005).

Although the NWHI represent a relatively intact tropical reef ecosystem, macroalgal community dynamics of the 10 atolls, islands, and reefs situated in the PMNM remain poorly understood. A study published in conjunction with the Third Northwestern Hawaiian Islands Scientific Symposium (Vroom and Page, 2006) was the first to provide distributional maps of common algal species, statistically compare sites from differing habitats and islands based on relative abundance of macroalgae, and identify temporal differences in macroalgal populations. Findings revealed that the abundance of most macroalgal genera was low across the archipelago, but that members of certain green algal genera including *Halimeda* and *Microdictyon* can be abundant and in some cases form dense monotypic meadows on the reef, especially in fore reef ar-

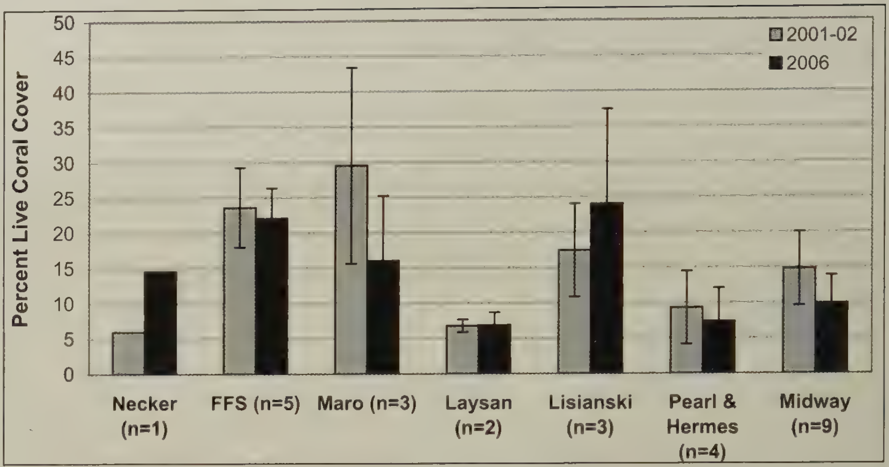


*Figure 9.32. Mean (± SE) coral cover at permanent transects for seven reefs and atolls in the NWHI conducted in 2001-2002 and again in 2006. Numbers presented beside location names are the number of transects sampled at the site during each time period (n= 27). Source: Maragos and Veit, USFWS unpub. data.*

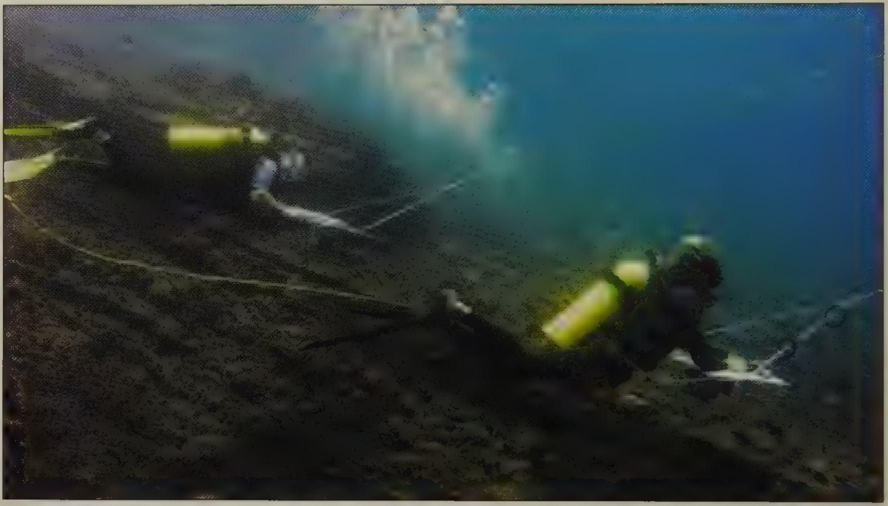


*Figure 9.33. Divers survey a reef while being towed by a boat. Photo: J. Kenyon.*

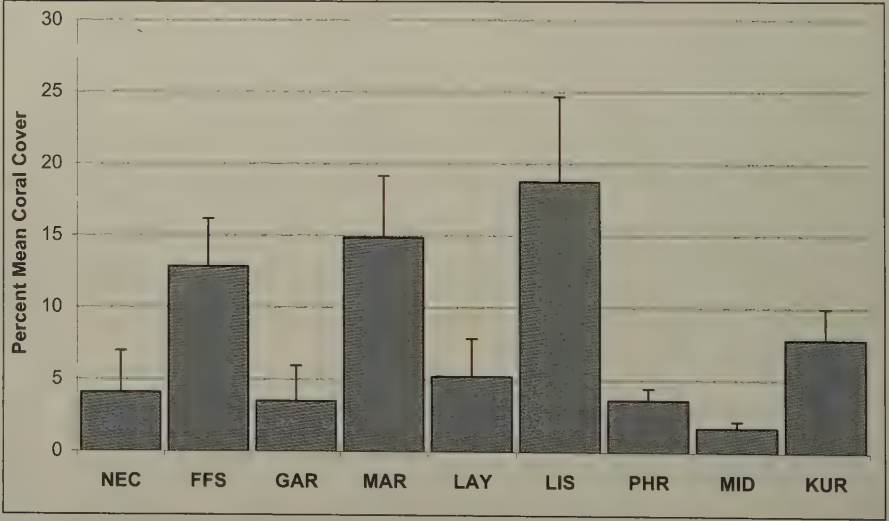


*Figure 9.34. Mean coral cover (± SE) among locations in the NWHI. Coral cover was calculated from analysis of imagery recorded at 30-second intervals during towed-diver surveys conducted in 2003. Source: PIFSC-CRED, unpub. data.*

eas (*Microdictyon*) and lagoons (*Halimeda*). Other genera, such as the brown algae *Stypopodium* and *Lobophora*, and the red alga *Laurencia*, became increasingly prevalent in the three northernmost atolls of the Hawaiian Archipelago (Kure, Midway, and Pearl and Hermes). Relative abundance of macroalgae across the NWHI as a whole remained relatively static for the years surveyed; however, slight changes occurred at Kure and Midway atolls, where coral bleaching events were documented in 2002 and 2004. Distributional maps of percent occurrence of 10 macroalgal genera spanning the years 2002 through 2006 are currently in production and will form part of PIFSC-CRED *Coral Reef Ecosystem Monitoring Report for the Hawaiian Archipelago: 2000-2007.*

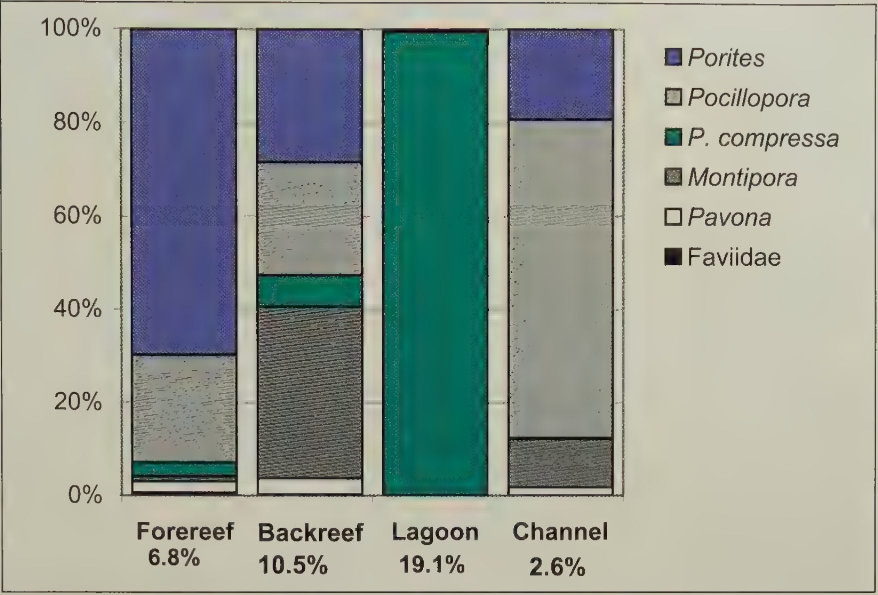


*Figure 9.35. Relative abundance of primary coral taxa by habitat at Pearl and Hermes Atoll, NWHI, derived from towed-diver surveys conducted in 2000 and 2002. Values below habitat labels are total coral percent cover within each habitat.* Porites *= massive and encrusting* Porites*;* P. compressa *=* Porites compressa*. Source: PIFSC-CRED, Kenyon et al., 2007.*

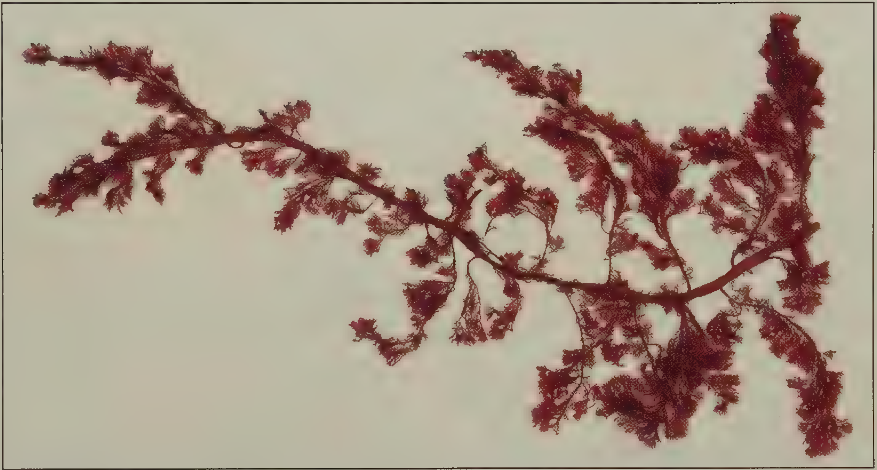


*Figure 9.36. Recent surveys have found one species of red algae new to science,* Dasya atropurpurea*. Photo: P. Vroom.*

A study recently completed at Pearl and Hermes Atoll (Page, 2006) used detailed species-level percent cover analyses coupled with environmental variables to better understand the mechanisms that determine distributional patterns of organisms, particularly algae. Benthic community composition was examined along a wave exposure gradient using multivariate statistical analyses with the expectation that sites with similar levels of wave exposure would exhibit similar benthic communities. Species richness of coral and macroalgae were also compared to determine if sites with intermediate levels of wave exposure would contain the highest diversity of these benthic organisms. To test these hypotheses, percent cover of sessile benthic organisms was determined at 34 sites in four wave exposure categories: high, intermediate-high, intermediate-low and low. Multivariate statistical analyses revealed that sites from each wave exposure category differed significantly, and a non-metric multi-dimensional scaling ordination (nMDS) and cluster diagram grouped sites from low, high and intermediate-high wave disturbance areas into three relatively discrete clusters. However, sites experiencing intermediate-low wave exposure did not group together in the nMDS ordination or cluster diagram, suggesting variability in benthic composition among these sites. Coral and macroalgal species richness was significantly higher at sites with intermediate-high and intermediate-low levels of wave exposure than at sites with low wave exposure, although not significantly higher than sites with high wave exposure.

Vroom et al. (2006) compared percent cover of macroalgal, turf algal, crustose coralline algal and coral populations at eight islands across the Pacific Basin, including two from the NWHI. The NWHI were documented to contain the highest percent cover of algal species when compared to other geographic locations, and the lowest percent cover of living coral. This is likely due to the subtropical location of the NWHI, which exposes reef communities to cool SSTs and relatively frequent extreme high wave energy events during winter months. Despite high algal populations, the NWHI remain healthy and thriving marine ecosystems that are dominated by top predators and high fish populations.

### *Habitat Mapping*

In support of the U.S. Coral Reef Task Force's mission to produce comprehensive digital maps of all shallow (<30 m depth) coral reef ecosystems in the United States and characterize priority moderate-depth (20-200 m) reef systems, NOAA has undertaken a comprehensive and collaborative mapping effort in the Pacific Islands Region. As key products of these efforts, NOAA's Center for Coastal Monitoring and Assessment, Biogeography Branch (CCMA-BB) produced a draft of the *Atlas of the Shallow-Water Benthic Habitats of the Northwestern Hawaiian Islands* (NOAA, 2003; Figure 9.37) and continues to provide public access to imagery, digital data, map products and estimated water depths for shallow-wa-

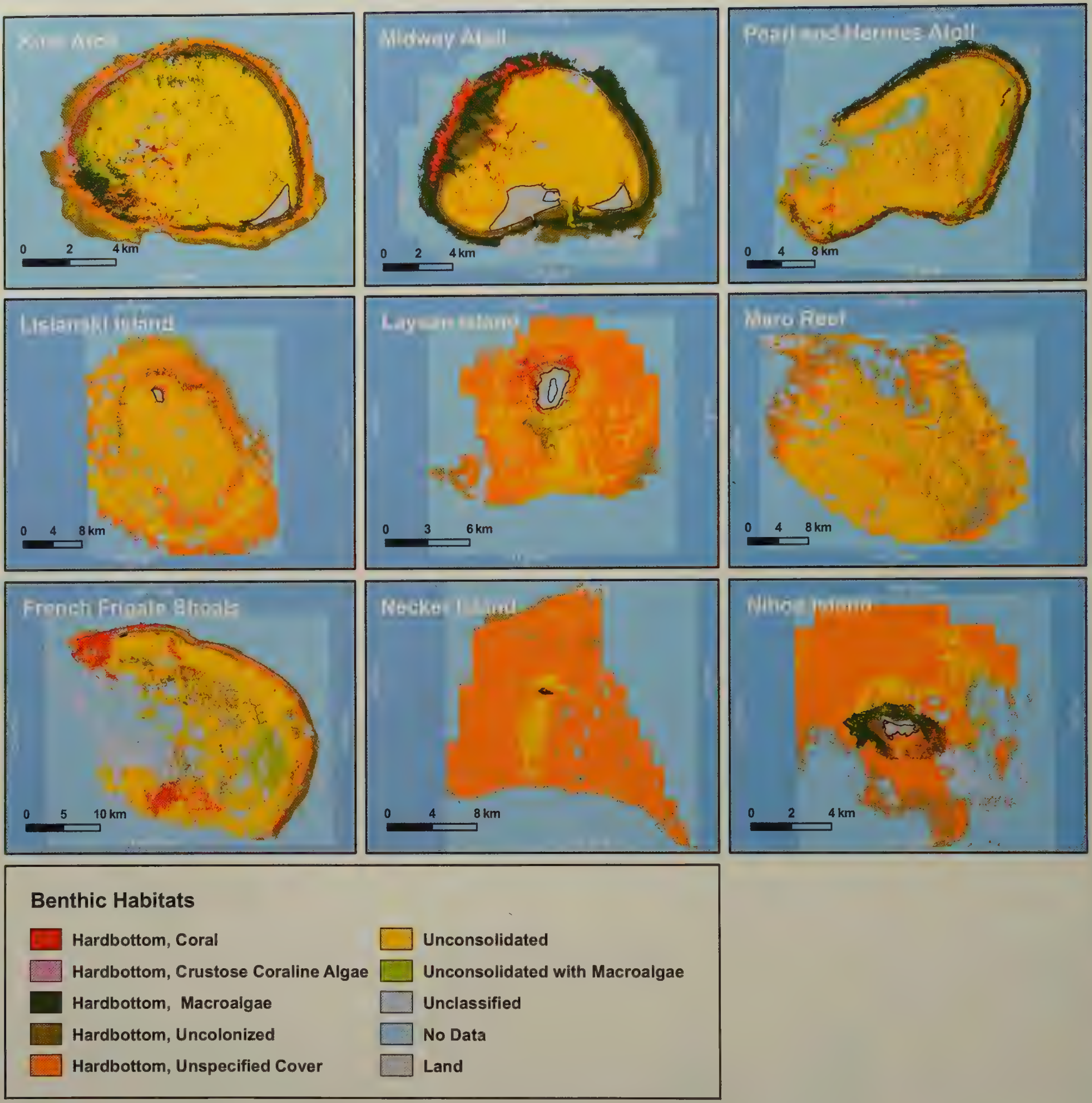

Kure Atoll
0 2 4 km
Midway Atoll
0 2 4 km
Pearl and Hermes Atoll
0 4 8 km
Lisianski Island
0 4 8 km
Laysan Island
0 3 6 km
Maro Reef
0 4 8 km
French Frigate Shoals
0 5 10 km
Necker Island
0 4 8 km
Nihoa Island
0 2 4 km
Benthic Habitats
Hardbottom, Coral
Hardbottom, Crustose Coraline Algae
Hardbottom, Macroalgae
Hardbottom, Uncolonized
Hardbottom, Unspecified Cover
Unconsolidated
Unconsolidated with Macroalgae
Unclassified
No Data
Land

*Figure 9.37. Benthic habitats in the NWHI by major habitat type. Data source: NOAA, 2003. Map: K. Buja.*

ter areas derived from IKONOS imagery by Stumpf et al. (2003). In a complementary effort, PIFSC-CRED produced *The Bathymetric Atlas of the Northwestern Hawaiian Islands* (Miller et al., 2003), which focuses on moderate-depth areas. Bathymetric data from 2003-2006 collected during NOAA Ship *Hiialakai* and R/V *Acoustic Habitat Investigator* surveys add to previously published reports. Table 9.10 presents the current status of multibeam bathymetric mapping in the NWHI.

*Table 9.10. NWHI Multibeam mapping statistics and estimates. Source: PIBHMC.*

| | MAPPING COMPLETED 2002-2006 | | ESTIMATE TO COMPLETE |
|---|---|---|---|
| | km² | Days | Days |
| Deep (100-5000 m) | 38,367 | 25 | 70 |
| Mid-Depth (10-100 m) | 3,709 | 124 | 285 |
| Totals | 42,076 | 149 | 355 |

Bathymetric grids at various resolutions are updated annually by the Pacific Islands Benthic Habitat Mapping Center (PIBHMC) and published at http://www.soest.hawaii.edu/pibhmc. Some bathymetric data have been collected and processed around each of the islands and banks in the NWHI in water depths ranging from 3-1000 m, with almost complete coverage around Kure, Midway, Pearl and Hermes, Brooks Banks, and French Frigate Shoals, and partial coverage at other locations. High resolution bathymetric surveys provide baseline depth data, as well as visual indications of the composition and features of the seafloor. The large bank on the southwest side of French Frigate Shoals, which lies in water depths between 15 and 100 m, was the first area to be thoroughly mapped in early 2005 and is used here to illustrate the various benthic habitat mapping products, their potential uses, and interpretation (Figure 9.38). Similar products for other banks are regularly added to the Web site as mapping, data processing, product and metadata generation, and interpretation are completed. As shown in Figure 9.38, the multibeam bathymetric data show complex patterns of sand waves, ridges and other bathymetric features, some of which are interpreted as coral patch reefs and confirmed with sparse optical validation observations. Bathymetric and optical validation data at French Frigate Shoals indicate the widespread presence of coral habitats in water depths as great as 40 m. Bathymetric and optical validation data from other NWHI banks and atolls also show a varying amount of complex hard substrate in these depths that may indicate coral presence.

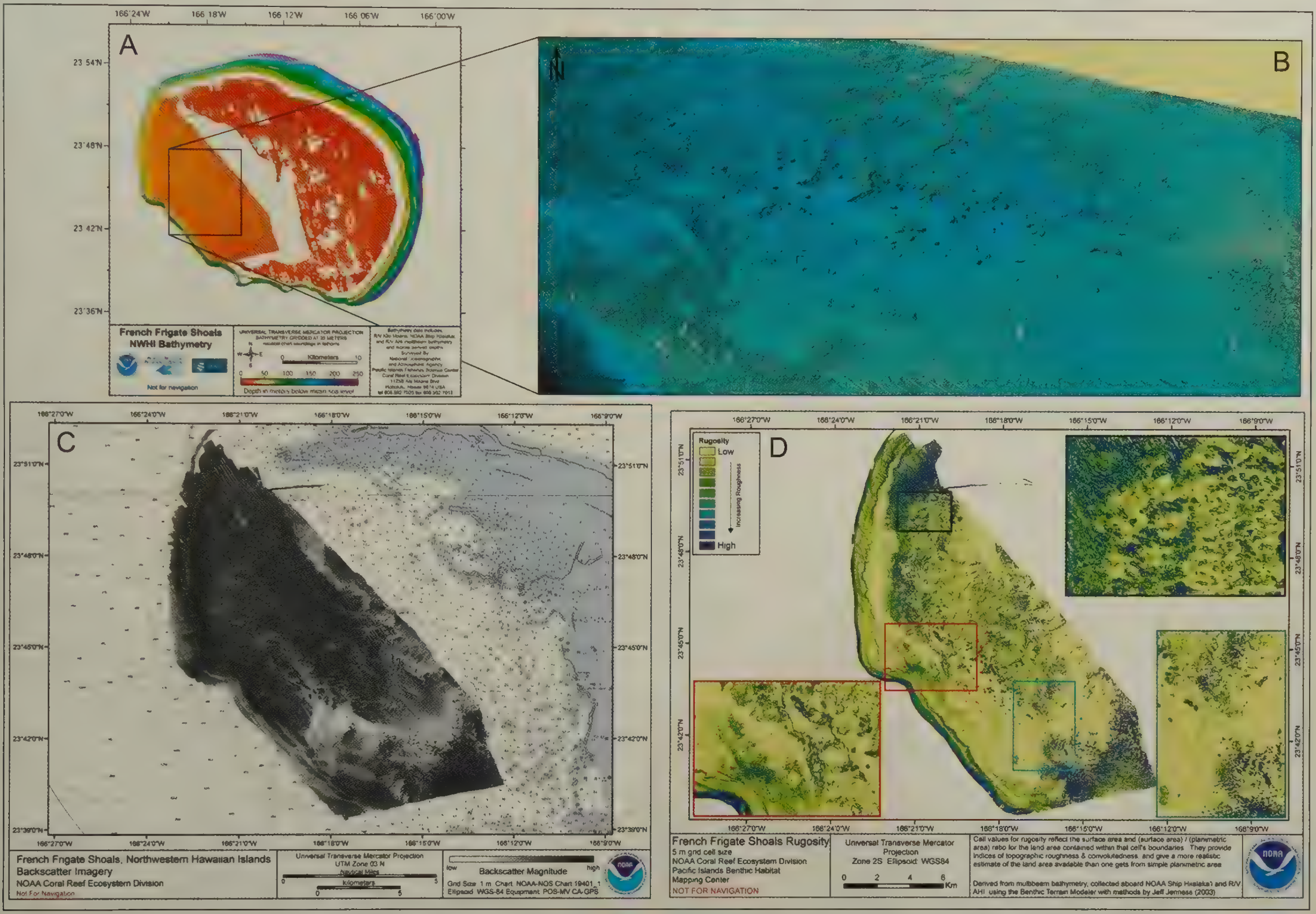

A
B
C
D
166°24'W
166°18'W
166°12'W
166°06'W
166°00'W
23°54'N
23°48'N
23°42'N
23°36'N
French Frigate Shoals
NWHI Bathymetry
Not for navigation
UNIVERSAL TRANSVERSE MERCATOR PROJECTION
Kilometers
0
10
0
50
100
150
200
250
Depth in meters below mean sea level
N
166°27'0"W
166°24'0"W
166°21'0"W
166°18'0"W
166°15'0"W
166°12'0"W
166°9'0"W
23°51'0"N
23°48'0"N
23°45'0"N
23°42'0"N
23°39'0"N
French Frigate Shoals, Northwestern Hawaiian Islands
Backscatter Imagery
NOAA Coral Reef Ecosystem Division
Not For Navigation
Universal Transverse Mercator Projection
UTM Zone 03 N
Nautical Miles
kilometers
0
5
low
high
Backscatter Magnitude
Grid Size 1 m Chart NOAA-NOS Chart 19401_1
Ellipsoid WGS-84 Equipment POS-MV CA-GPS
Rugosity
Low
Increasing Roughness
High
French Frigate Shoals Rugosity
5 m grid cell size
NOAA Coral Reef Ecosystem Division
Pacific Islands Benthic Habitat
Mapping Center
NOT FOR NAVIGATION
Universal Transverse Mercator
Projection
Zone 2S Ellipsoid WGS84
0
2
4
6
Km
Cell values for rugosity reflect the surface area and (surface area) / (planimetric area) ratio for the land area contained within that cell's boundaries. They provide indices of topographic roughness & convolutedness, and give a more realistic estimate of the land area available than one gets from simple planimetric area
Derived from multibeam bathymetry, collected aboard NOAA Ship Hi'ialakai and R/V AHI using the Benthic Terrain Modeler with methods by Jeff Jenness (2003)

*Figure 9.38. Multibeam bathymetric data at French Frigate Shoals show complex seafloor features including sand, waves and coral heads and ridges. Box outlined in panel A indicates location of detailed bathymetric image in panel B. Panel C shows multibeam backscatter data, which provide additional information about the hardness and roughness of the seafloor. High backscatter returns (dark) indicate hard substrate (e.g., pavement or coral), while lower returns (light) indicate softer substrate (e.g. sand). Panel D shows derivative data products (e.g., slope, rugosity and Bathymetric Position Index) which help identify geomorphological characteristics that may determine benthic habitat utilization. French Frigate Shoals shows high rugosity in many areas of the bank top, corresponding to areas of high bathymetric complexity and possible coral presence. Source: PIBHMC.*

Optical validation data (Figure 9.39) that have been collected since 2001 at French Frigate Shoals aid scientists in interpretation of seafloor characteristics. Video and still photographic data are interpreted according to a benthic habitat classification scheme that was designed to include indications of substrate, living cover, coral type and other factors that may influence habitat utilization, as documented at ftp://ftp.soest.hawaii.edu/pibhmc/website/webdocs/webtext&figures/bh_class_codes.htm. While the individual data products, such as multibeam bathymetry, backscatter, geomorphological derivatives, and optical validation, are useful individually, combining the different data types allows interpretation of seafloor characteristics and creation of seafloor characterization maps, such as in Figure 9.40. This interpretation of soft and hard substrate results from concurrent analysis of bathymetric, backscatter and optical validation data.

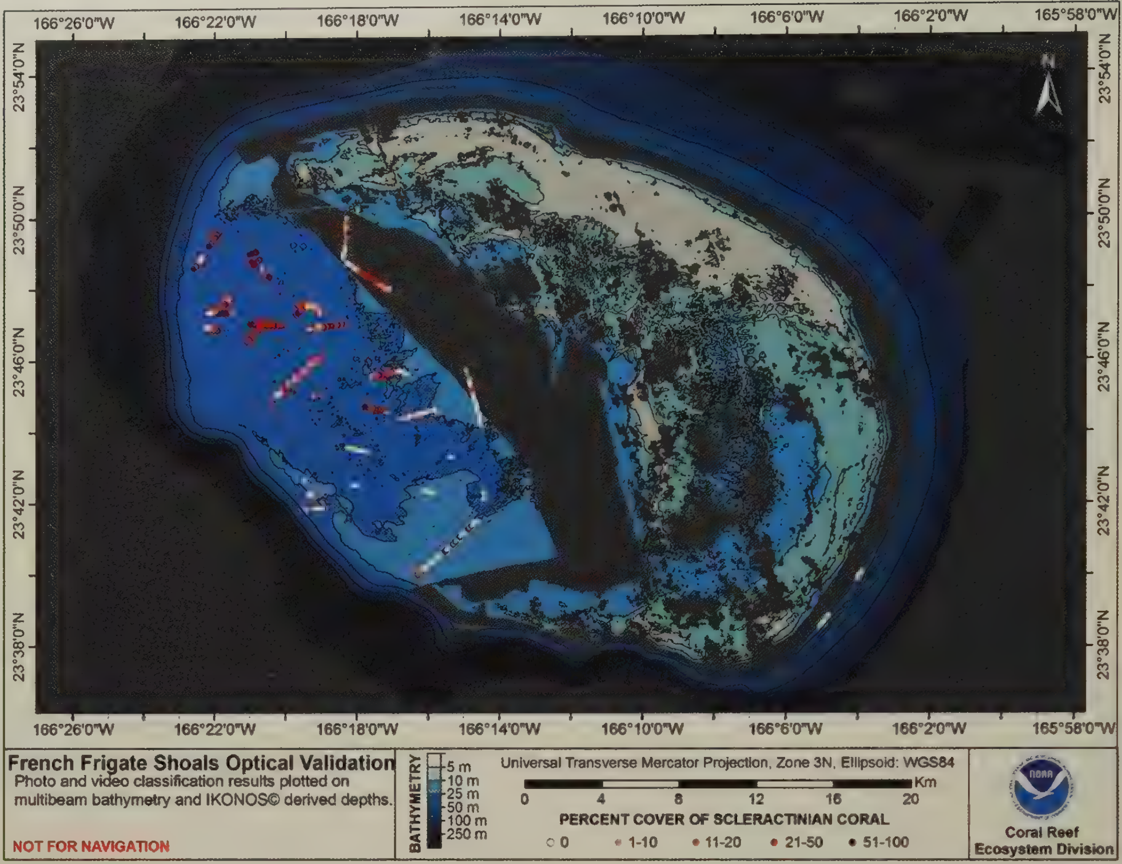

166°26'0"W
166°22'0"W
166°18'0"W
166°14'0"W
166°10'0"W
166°6'0"W
166°2'0"W
165°58'0"W
23°54'0"N
23°50'0"N
23°46'0"N
23°42'0"N
23°38'0"N
N
French Frigate Shoals Optical Validation
Photo and video classification results plotted on multibeam bathymetry and IKONOS© derived depths.
NOT FOR NAVIGATION
BATHYMETRY
5 m
10 m
25 m
50 m
100 m
250 m
Universal Transverse Mercator Projection, Zone 3N, Ellipsoid: WGS84
Km
0
4
8
12
16
20
PERCENT COVER OF SCLERACTINIAN CORAL
○ 0
● 1-10
● 11-20
● 21-50
● 51-100
Coral Reef Ecosystem Division

Figure 9.39. Percent coral cover as interpreted from optical validation data collected at French Frigate Shoals. Source: PIFSC-CRED.

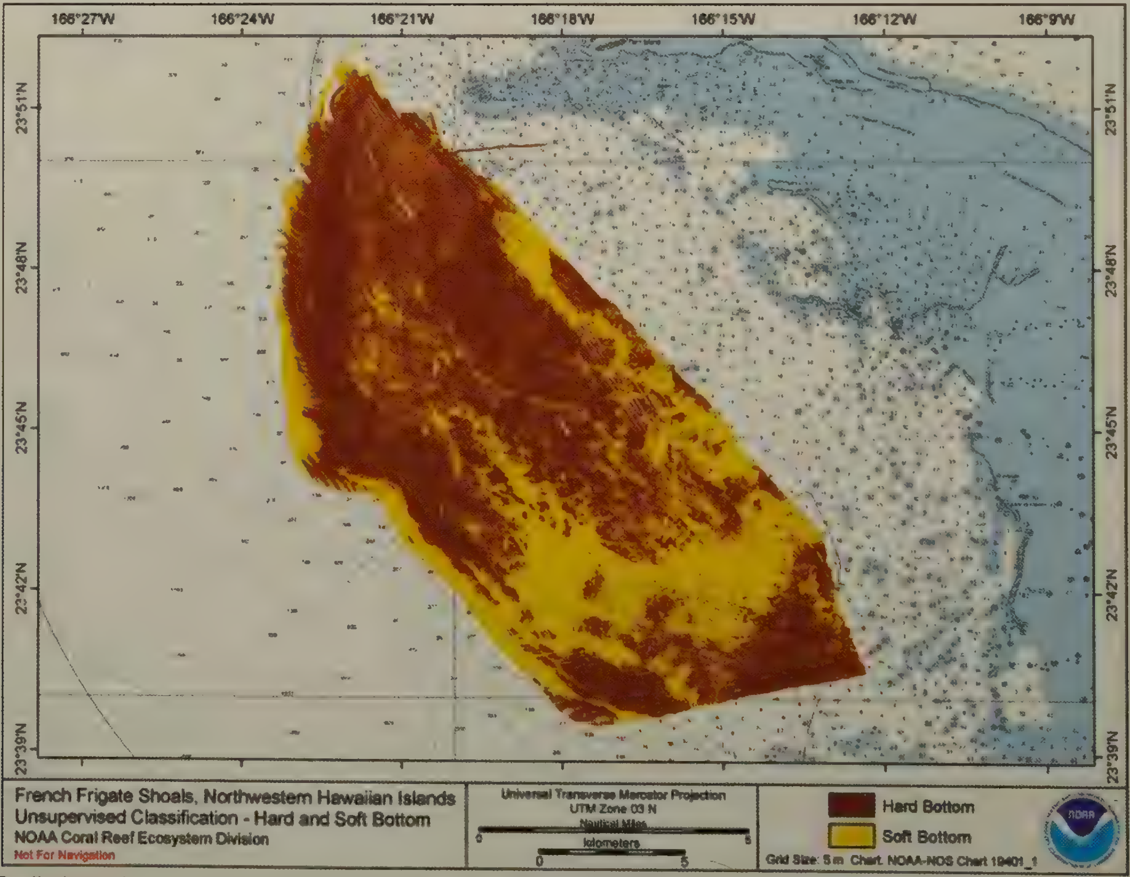

166°27'W
166°24'W
166°21'W
166°18'W
166°15'W
166°12'W
166°9'W
23°51'N
23°48'N
23°45'N
23°42'N
23°39'N
French Frigate Shoals, Northwestern Hawaiian Islands
Unsupervised Classification - Hard and Soft Bottom
NOAA Coral Reef Ecosystem Division
Not For Navigation
Universal Transverse Mercator Projection
UTM Zone 03 N
Nautical Miles
0
5
kilometers
0
5
Hard Bottom
Soft Bottom
Grid Size: 5 m Chart: NOAA-NOS Chart 19401_1

Figure 9.40. Preliminary hard and soft seafloor substrate map derived from an unsupervised classification of multibeam backscatter and bathymetry derivatives at FFS. Initial supervised classifications of backscatter data into hard and soft areas based on photographs were used to define the unsupervised class types and to evaluate map accuracy. Derivatives such as these are being used to improve sampling techniques for long-term ecosystem monitoring, to guide future groundtruthing operations, and to identify coral-rich and species specific environments in the NWHI. Source: PIFSC-CRED.

## ASSOCIATED BIOLOGICAL COMMUNITIES

### FISHES

*Fish Assemblage Structure*

The similarity of fish assemblages among reefs in the NWHI was compared based on numerical abundance of each species at each reef (Figure 9.41). The three true atolls (Kure, Midway, and Pearl and Hermes) and the one partial atoll (French Frigate Shoals) had high concordance and formed a distinct cluster in ordination space. The three basalt pinnacles (Nihoa, Necker and Gardner) were also similar in their fish assemblages (based on numerical density) but differed from each other more so than did the three atolls, resulting in lower spatial concordance. Maro Reef and Lisianski Island-Neva Shoal had similar fish assemblages and clustered together in a distinct grouping. Laysan Island is the only coral cay in the NWHI and had a somewhat unique fish assemblage.

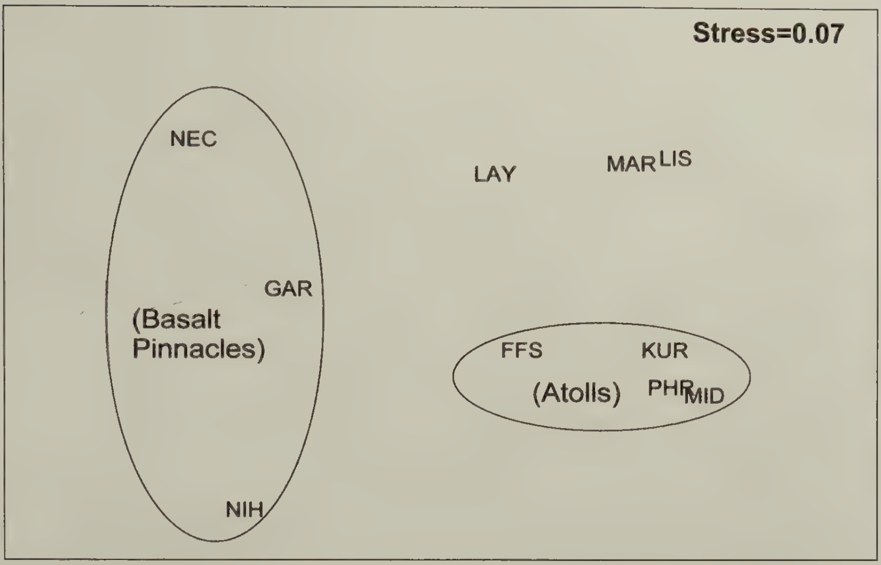


*Figure 9.41. Non-metric multi-dimensional scaling plot of reef similarities derived from numerical abundance of fish species. Similarities based on Bray-Curtis Similarity Index. Numerical abundance values are square root transformed. Source: Friedlander and DeMartini, in prep.*

*Species Richness Patterns of Reef Fishes*

A total of 612 reef and shore fishes have recently been reported from the MHI (Randall, 2007) while 258 are documented from Midway Atoll in the NWHI (Randall et al., 1993). Despite these differences, the total number of species observed on quantitative transects in the NWHI (n=210) was similar to the 215 species reported in a recent comprehensive quantitative study around the MHI (Friedlander et al., 2005, 2007). The lowest overall fish species richness in the NWHI occurs at the small basalt islands (Nihoa, Necker and Gardner) and is highest at French Frigate Shoals and Pearl and Hermes. The values at French Frigate Shoals may be related to the higher coral richness and greater diversity of habitats (Maragos et al., 2004) while high values at Pearl and Hermes is likely related to the atoll's large size, habitat diversity and presence of subtropical and temperate species which occur at greater depths southward.

Total species richness observed on surveys showed a positive and linear relationship with the total area of reef in waters <18 m (ln(x+1); Figure 9.42). This relationship is consistent with most theories of island biogeography and likely reflects the greater diversity of habitats at larger islands.

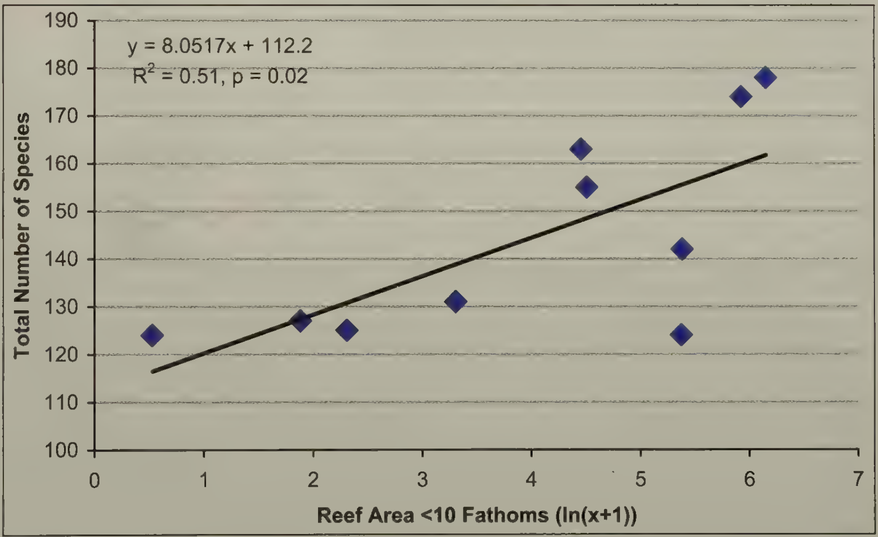


*Figure 9.42. Relationship between number of fish species at each reef and total reef area <18 m (10 fathoms). Source: Friedlander and DeMartini, in prep.*

*Biogeographic Patterns Based on Latitude*

A total of 30 species showed a significant positive correlation (Spearman Rank Correlation, $p<0.05$) with latitude based on numerical density from Northwestern Hawaiian Resource Assessment and Monitoring Program (NOWRAMP) quantitative fish surveys between 2000 and 2002. Of these, 17 (57%) were endemics. Wrasses (Labridae) had the greatest number of species (eight) that exhibited a higher latitude bias, followed by damselfishes (Pomacentridae) with four species. Several other species such as knifejaws (*Oplegnathus* spp.) and boarfish (*Evistias acutirostris*), were more abundant at higher latitudes but the low numbers of these species recorded during surveys made statistical results inconclusive.

Over 63% of the total numerical abundance of fishes at Kure Atoll was composed of species with a high latitude correlation (Figure 9.43). The percentage of high latitude biased individuals was also substantial at Midway Atoll (56%), Pearl and Hermes Atoll (52%), and Lisianski Island-Neva Shoals (53%). A major faunal break seems to occur between Maro Reef and Gardner Pinnacles with the numerical abundance of high latitude bias species dropping from 52% to 25% between these two locations. The lowest percentage of high latitude biased individuals was observed at Nihoa Island (13%). According to this analysis, another less dramatic faunal break seems to be present between Nihoa (13%) and Mokumanamana (Necker Island; 28%).

Of the 30 species analyzed, 21 were significantly and positively correlated ($p<0.05$) with low latitudes based on numerical density from NWHI RAMP quantitative fish surveys between 2000 and 2002. Only two of these species (9%) were endemics in contrast to the species with high latitude bias, where 54% were endemic. Based on total numerical abundance, the highest percentage of low latitude species was observed at Mokumanamana (28%) and Nihoa (14%; Figure 9.43). Less than 1% of the numerical density of fishes at Midway consisted of species with a low latitude preference. Similarly, Kure Atoll (1.2%), Pearl and Hermes Atoll (2.0%) and Lisianski Island-Neva Shoals (3.2%) had low numbers of more tropical fish species.

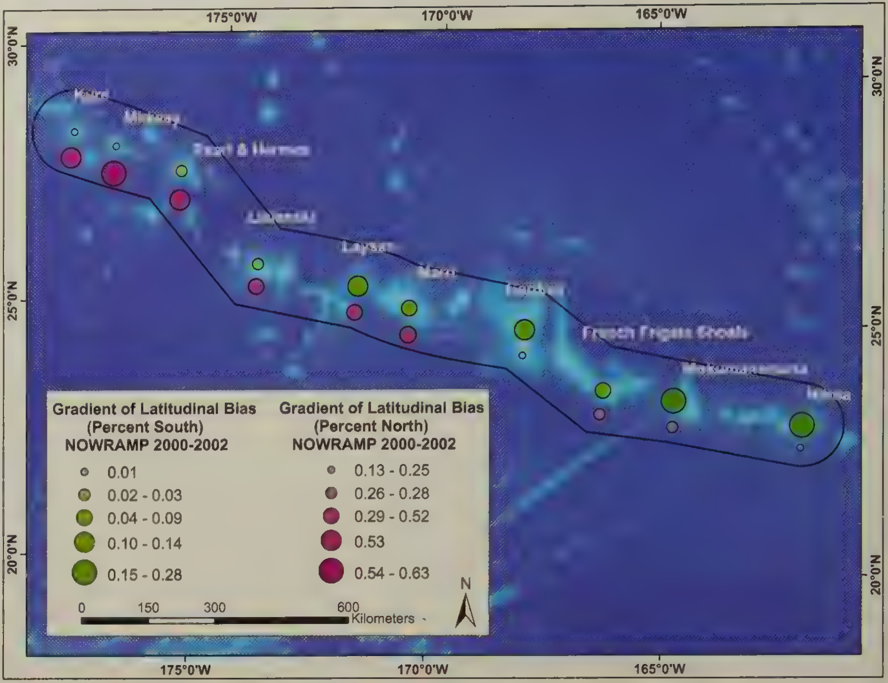


*Figure 9.43. Latitudinal bias of reef fishes in the NWHI. Green circles are percentages of species that have a significant tropical bias. Pink circles are percentages of species that have a significant temperate bias. Source: Friedlander and DeMartini, in prep.*

*Temporal Trends in Fish Assemblages 2000-2005*

Fish assemblage structure in the NWHI was examined for temporal trends between 2000 and 2005. Analysis was limited to only those reefs and stations that were initially sampled during the 2000-2002 assessment phase and then sampled again in subsequent years. Under these criteria, reefs examined included Maro, French Frigate Shoals, Pearl and Hermes, Kure and Midway. At each of these reefs, stations were only included that were sampled initially (2000-2002) and again in all subsequent years (2003, 2004 and 2005).

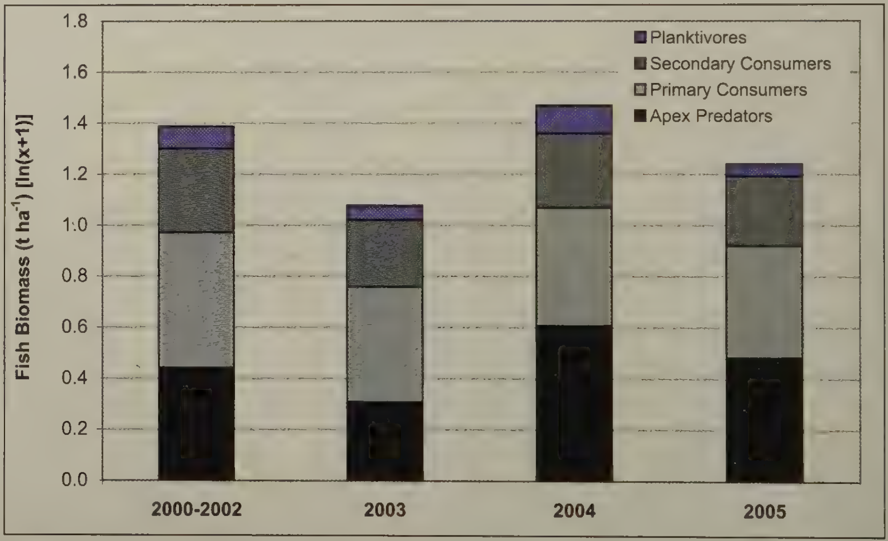


*Figure 9.44. Fish biomass and trophic guilds from 2000-2005. Analysis limited to locations initially sampled during the 2000-2002 assessment phase and sampled again in subsequent years. Source: PIFSC-CRED, unpub. data.*

Overall, apex predators accounted for 35% of the total biomass at long-term sites sampled in all years (Figure 9.44). Many of the sites visited consistently were lagoon and back reef locations in addition to some fore reef sites. Protection from surf meant that these sites could be sampled on a more regular basis than some of the fore reef locations, which were exposed and inaccessible during certain years. Apex predators account for over 55% of the total biomass on the fore reef (Friedlander and DeMartini, 2002) and the lower values observed in sheltered sites reflect a greater sampling effort in habitats that normally harbor fewer predators. Primary consumers comprised 38% of the total biomass across all monitoring sites in this analysis and is likely related to the higher abundance of macroalgae cover and hence increased food availability in these sheltered habitats. Overall abundance of planktivores (6%) is lower in sheltered habitats where plankton availability is lower.

There were no significant differences in the biomass among years for apex predators ($F_{3,215}=2.48$, $p=0.06$), planktivores ($F_{3,215}=2.29$, $p=0.08$), primary consumers ($F_{3,215}=0.92$, $p=0.43$), or secondary consumers ($F_{3,215}=1.25$, $p=0.29$). However, total biomass among years was marginally significantly different ($F_{3,215}=2.81$, $p=0.04$) but the only significant pair-wise difference was between 2004 and 2003 (2004>2003, $p<0.05$). This difference was driven mainly by lower apex predator biomass values recorded in 2003.

*Movement Patterns of Top Predators*

In 2005 and 2006, 122 top predators of seven species with surgically-implanted acoustic transmitters were monitored for movement using 17 underwater receivers stationed on the seabed at five atolls within the PMNM. In 2006, nine sharks (five tiger sharks and four Galapagos sharks) were equipped with satellite transmitters to monitor their movements in locations not equipped with acoustic receivers. Using these technologies, tiger sharks were found to routinely swim between atolls, range along the entire Hawaiian archipelago and venture hundreds of kilometers beyond PMNM boundaries into open ocean. The first empirical evidence of gray reef sharks swimming across open ocean between atolls was also documented.

Other top predator species appeared to be site-attached to individual atolls, but wide-ranging within their "home" atoll (Meyer et al., 2007a,b). Ulua (giant trevally, *Caranx ignobilis*) and uku (jobfish, *Aprion virescens*) had predictable patterns of movement, including diel habitat shifts and tidal and lunar rhythmicity (Figure 9.45; Meyer et al., 2007a). During summer full moons, ulua from all over French Frigate Shoals converge on one particular location, where they form large spawning aggregations (Figure 9.46, Meyer et al., 2007a).

*Recruitment*

Planktonic dispersal of reef fishes is an important process linked to the persistence of benthic reef populations. Recruitment of reef fishes increased with latitude, and was especially pronounced at the four northernmost reefs, which had a larger proportion of young-of-year (YOY) recruits (DeMartini and Friedlander, 2004). During 2000-2002, recruit fish densities were somewhat greater to the northwest portion of the archipelago compared to the southeast, and a larger number of endemic (versus non-endemic) species recruited to a greater extent in the northwest portion of the NWHI (Figure 9.47; DeMartini and Friedlander, 2004). This was first indicated by survey data collected during the 1990s at French Frigate Shoals and Midway (DeMartini et al., 2002; DeMartini, 2004), where consistently higher recruitment of YOY life stages of fishes occurred at Midway Atoll, despite the generally greater densities of older-stage fishes at French Frigate Shoals.

Disproportionate recruitment at higher-latitude reefs may be related to higher levels of within-reef and regional reseeding at higher latitudes. Ecologically significant levels of dispersal have been documented to be on the scale of 50 to 100 km for most species with a relatively high rate of local retention or recruitment from adjacent locations (Cowen et al., 2006). Hence, based on the genetic evidence, current patterns and scales of ecological connectivity, the NWHI are not likely a sufficient or consistent source to replenish stocks in the MHI, although sporadic contributions are possible and need to be investigated more thoroughly (Grigg et al., 2008).

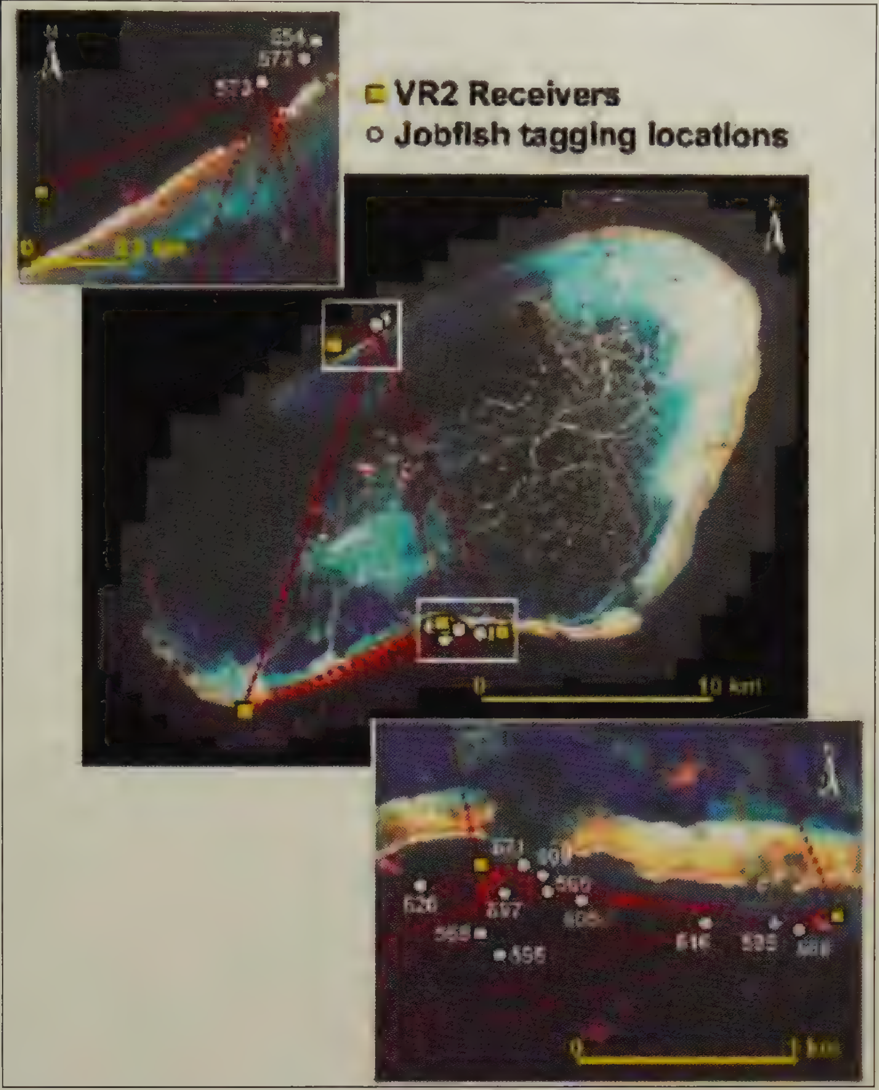


Figure 9.45. *Trans-atoll movements of uku (green jobfish,* Aprion virescens*) at Pearl and Hermes Reef. Yellow squares indicate locations of VR2 acoustic receivers, white circles indicate uku capture sites. Insets show enlarged view of capture areas with white numbers indicating the transmitter code of each uku. Dashed red lines indicate most direct route between uku release and detection locations. Source: Meyer et al., 2007b.*

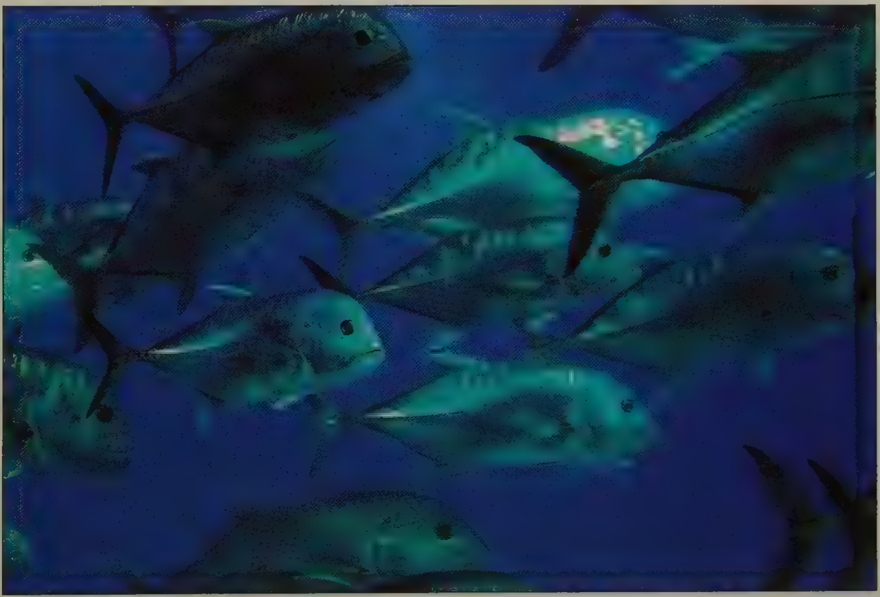


Figure 9.46. *Spawning aggregation of giant trevally (*Caranx ignobilis*) at French Frigate Shoals, May 23, 2006. Photo: Jill Zamzow.*

### Connectivity Studies

Molecular genetic markers are currently being examined to resolve population and evolutionary partitions of fishes and invertebrates in the NWHI. Preliminary results indicate large differences among taxa in their degree of genetic connectivity throughout the archipelago. Some species appear to move around the archipelago with relative ease and show no significant genetic population structure in the NWHI and MHI (e.g., reef fish–Schultz et al., 2007; Craig et al., 2007). Other species show strong population structure, including the endemic Hawaiian grouper (Rivera et al., 2004) and spinner dolphins (Andrews et al., 2006).

Opihi, the endemic Hawaiian limpets (*Cellana exarata*, *C. sandwicensis* and *C. talcosa*) show striking population differentiation between the MHI and NWHI (Bird et al., 2007; Figure 9.48). For all three species, significant differentiation of populations occurs across the Hawaiian Archipelago, but the spatial scales, patterns and magnitudes of partitioning differ by almost an order of magnitude among species. Preliminary data from hermit crabs (Baums et al., unpub. data) indicate variable genetic connectivity in this group as well. In terms of management implications, there is significant population differentiation between the MHI and NWHI for all three species of opihi, and estimates of dispersal (migrants per generation ≤3) are too low to augment depleted MHI populations. Within the MHI, one species (*C. talcosa*) shows such strong population differentiation that if the Kauai population were depleted, the species could not likely recover within our lifetime (Bird et al., 2007).

Johnston Atoll, about 1,300 km southwest of Oahu, shows a strong biodiversity linkage with the Hawaiian Archipelago (Figure 9.49). Kobayashi (2006) used a computer simulation to infer patterns of larval dispersal between Johnston and the Hawaiian Archipelago, identifying a "northern corridor" which connects Johnston and the central portion of the NWHI and a "southern corridor" which connects Johnston to the MHI. Preliminary genetic data for the sea cucumber *Holothuria atra* showed that connectivity is very low between Oahu and French Frigate Shoals and between Oahu and Johnston. (Skillings et al., in prep.). In contrast, there was no significant difference between samples from French Frigate Shoals and Johnston. This supports the northern corridor theory of dispersal and a hypothesis first advanced by Grigg (1981) that Johnston is a potential gateway for enhancing biodiversity in the NWHI.

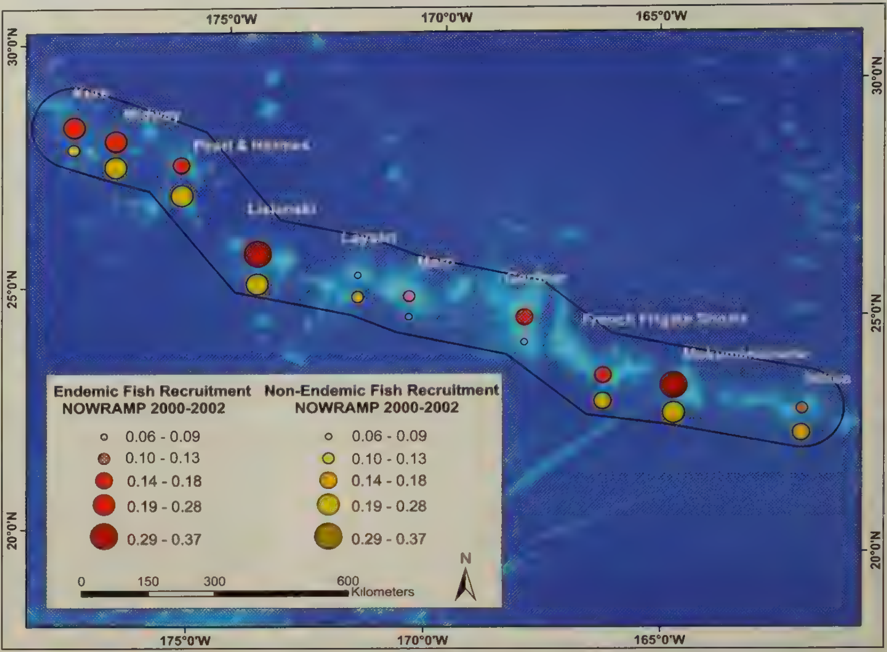


Figure 9.47. Geographic patterns of the Recruit Index (ratio of YOY sized to larger individuals) for all pooled major species of endemic and non-endemic reef fishes. Source: DeMartini and Friedlander, 2004.

Figure 9.48. A yellowfoot opihi (Cellana sandwicensis) at Kauai. All Hawaiian Cellana spp. are endemic to the archipelago (left). Photo: C. E. Bird. Tinker's butterflyfish (Chaetodon tinkeri) at Johnston Island (right). This species is endemic to Johnston and the Hawaiian Islands, illustrating the biodiversity links between the two regions. Photo: L.A. Rocha, HIMB.

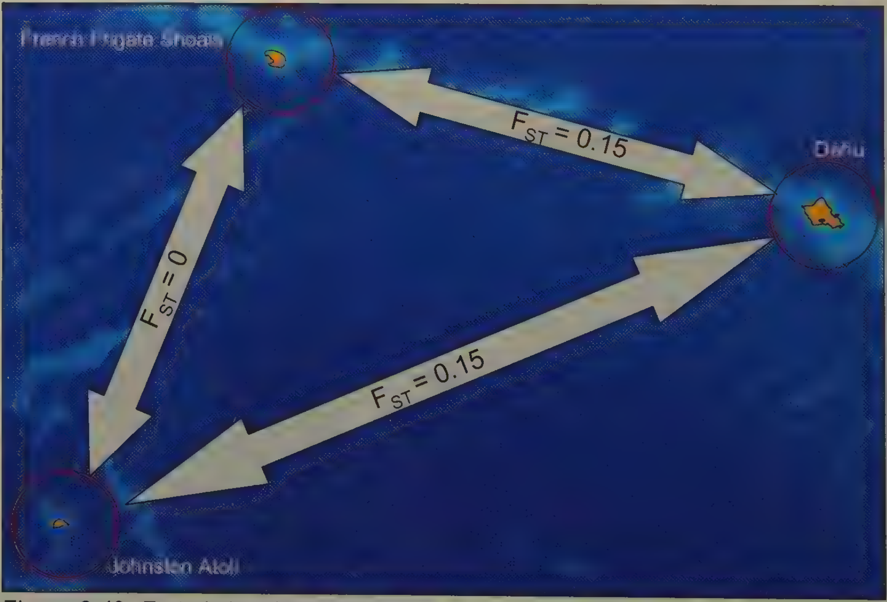


Figure 9.49. F-statistics demonstrate population genetic separations between the Oahu (MHI) and French Frigate Shoals (NWHI), and between the MHI and Johnston, but high connectivity between Johnston and French Frigate Shoals. Source: Skillings et al., in prep.

Results thus far indicate that population structure across the Hawaiian Archipelago does not fit a simple isolation-by-distance model, and generalizations based on average (geostrophic) oceanographic currents may not be warranted. Closely-related species with similar ecology and reproductive biology (such as opihi and hermit crabs) can have dramatically different patterns of genetic connectivity (Bird et al., 2007; Rocha et al., 2007). Together, these results necessitate that a suite of invertebrates and fishes be surveyed to resolve general trends, and to provide connectivity information pertinent to management of the PMNM (Figure 9.48).

### *Coral Ecosystem Health and Value*

An evaluation of the "health" and "value" of the reefs of the PMNM was conducted using previously published data on reef fish biomass, reef fish endemism, total living coral cover, numbers of the endangered Hawaiian monk seal (*Monachus schauinslandi*), and number of female green sea turtles (*Chelonia mydas*) nesting annually on each island as metrics (Jokiel and Rodgers, 2007). These data sets were used to construct an integrated scoring and ranking scheme for all islands. Results show that French Frigate Shoals had the highest score among all NWHI reefs, followed by Pearl and Hermes Atoll and Lisianski/Neva Shoal (Figure 9.50). These locations possess the largest reef area within the Monument and also contain a wide diversity of habitats including sheltered lagoons, sandy beaches and patch reefs. The two basalt islands of Nihoa and Necker had the lowest scores due to the limited nesting habitat available to turtles and seals, the small amount of shallow reef habitat and a lack of sheltered areas.

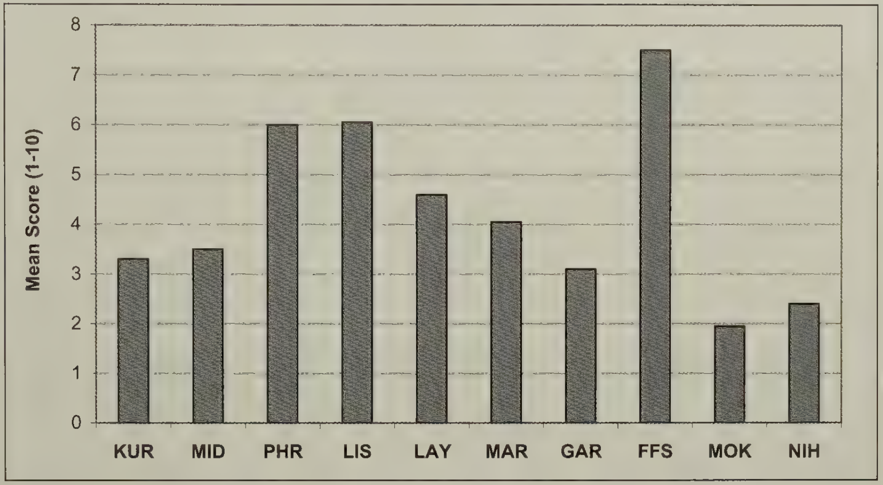


*Figure 9.50. Island ranking in the PMNM. Mean score based on scale of 0-10. Source: Jokiel and Rodgers, 2007.*

## NON-CORAL INVERTEBRATES

Recent efforts to quantify the non-coral invertebrate populations in the NWHI included two broad-scale towed-diver surveys conducted in 2004 and 2006 and a REA survey conducted in 2005. Surveys were focused on collecting information on three target classes of invertebrates: Echinoidea (sea urchins), Holothuroidea (sea cucumbers) and Asteroidea (sea stars). Towed-diver surveys found densities of echinoids and holothuroids to be highest at the northernmost islands/atolls. Sea urchins were the most common invertebrate observed during these surveys, with Kure (2004 and 2006) and Midway (2006) reporting the highest densities in the island chain (>1,600 urchins/hectare; Figure 9.51). Sea cucumbers were present at all islands but in low densities, with the exception of the northern atolls. The highest sea cucumber density was recorded at Kure in 2006 (Figure 9.51). Crown-of-thorns sea stars (COTS), were in relatively low abundance throughout the archipelago with the highest density recorded in 2004 at Pearl and Hermes (Figure 9.51). Though abundance of COTS was relatively low in comparison with reported infestation levels in areas of high coral cover such as the Great Barrier Reef, the impact of even low numbers of COTS in the NWHI could be significant given the relatively low coral cover found throughout the NWHI.

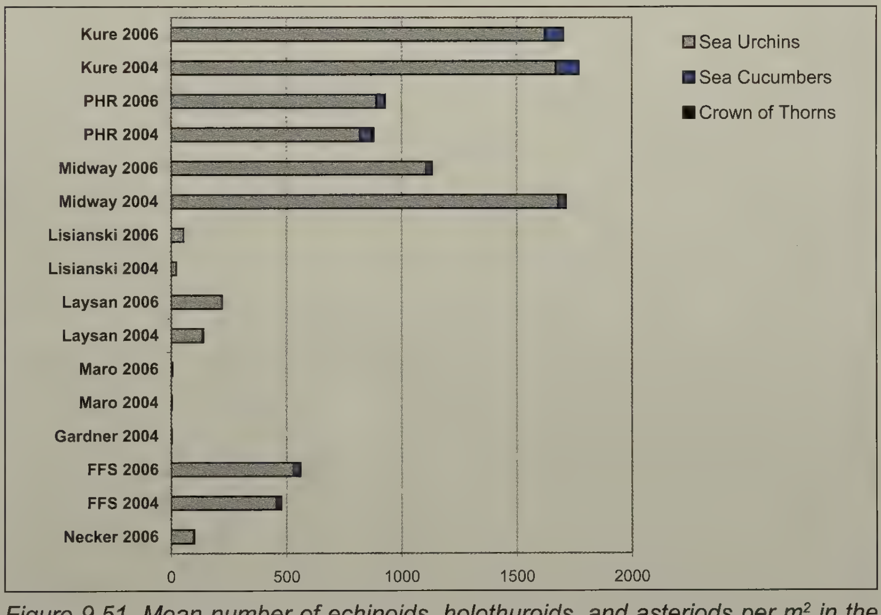


*Figure 9.51. Mean number of echinoids, holothuroids, and asteriods per m² in the NWHI from towed-diver surveys. Source: PIFSC-CRED, unpub. data.*

Data collected during REA surveys included species level information on the three target classes of invertebrates and followed the general patterns of the towed-diver data (Figure 9.52). The most common echinoid throughout the NWHI was the burrowing sea urchin, *Echinostrephus* sp., with the highest densities recorded at Midway and Kure (>12 individuals/m$^2$; Figure 9.52). As in towed-diver surveys, sea cucumbers were present at all islands/atolls but in low densities. The most common sea cucumber was *Actinopyga obesa*, with a density of 0.03 individuals/m$^2$ at Kure. The most common sea star was *Linckia multifora*.

### Census of Marine Life (CoML)

The international CoML is a global effort to assess the diversity, distribution, and abundance of ocean life and explain how it changes over time. Over 1,700 scientists from 73 countries are pooling their findings to create a comprehensive and authoritative portrait of life in the oceans today, yesterday and tomorrow. As one of 17 projects of the CoML, the goals of the Census of Coral Reef Ecosystems (CReefs) are to increase tropical taxonomic expertise, conduct a taxonomically-diversified global census of coral reef ecosystems and unify and improve access to coral reef ecosystem information scattered throughout the world. As part of the CReefs effort, PIFSC-CRED led a multi-institutional team of international taxonomists on a 23-day research expedition in October 2006 to explore the biodiversity of small, understudied, or lesser known invertebrate, algal and microbial species at French Frigate Shoals. In an effort to maximize the ability to document biodiversity, surveys were conducted at over 50 sites representing 14 habitat types using 12 sampling methods, including baited traps, rubble brushing, rubble extraction, underwater vacuuming, plankton tows, light traps, sediment and water sampling and other methods specifically designed to minimize habitat impacts while maximizing the number of ecological niches sampled.

Although thorough taxonomic identifications and molecular analyses of the samples collected will take many years to complete, preliminary findings suggested that approximately 2,300 unique morphospecies were collected and photographed during the 16 days of sampling (Figure 9.53). To improve the long-term ability to monitor biodiversity, tissue samples for molecular barcoding were collected from about 60% of the unique morphospecies. An estimated 30-50 collected specimens are thought to be new species to science, including new species of crabs, corals, sea cucumbers, sea quirts, worms, sea stars, snails and clams. From this expedition, well over a hundred new species records, including sponges, corals, anemones, flatworms, segmented worms, hermit crabs, crabs, sea slugs, bivalves, gastropods, octopus, sea cucumbers, sea stars and sea squirts, will likely be identified for FFS. The highest sampled diversity at FFS was within the phyla Anthropoda and Mollusca. By habitat type, lagoon patch reefs, La Perouse Pinnacle (basalt), back reef and deep fore reefs had the highest diversity. Due to the high level of taxonomic expertise, hand collection was the most effective sampling methodology, following by rubble extraction, rubble brushing and use of baited traps.

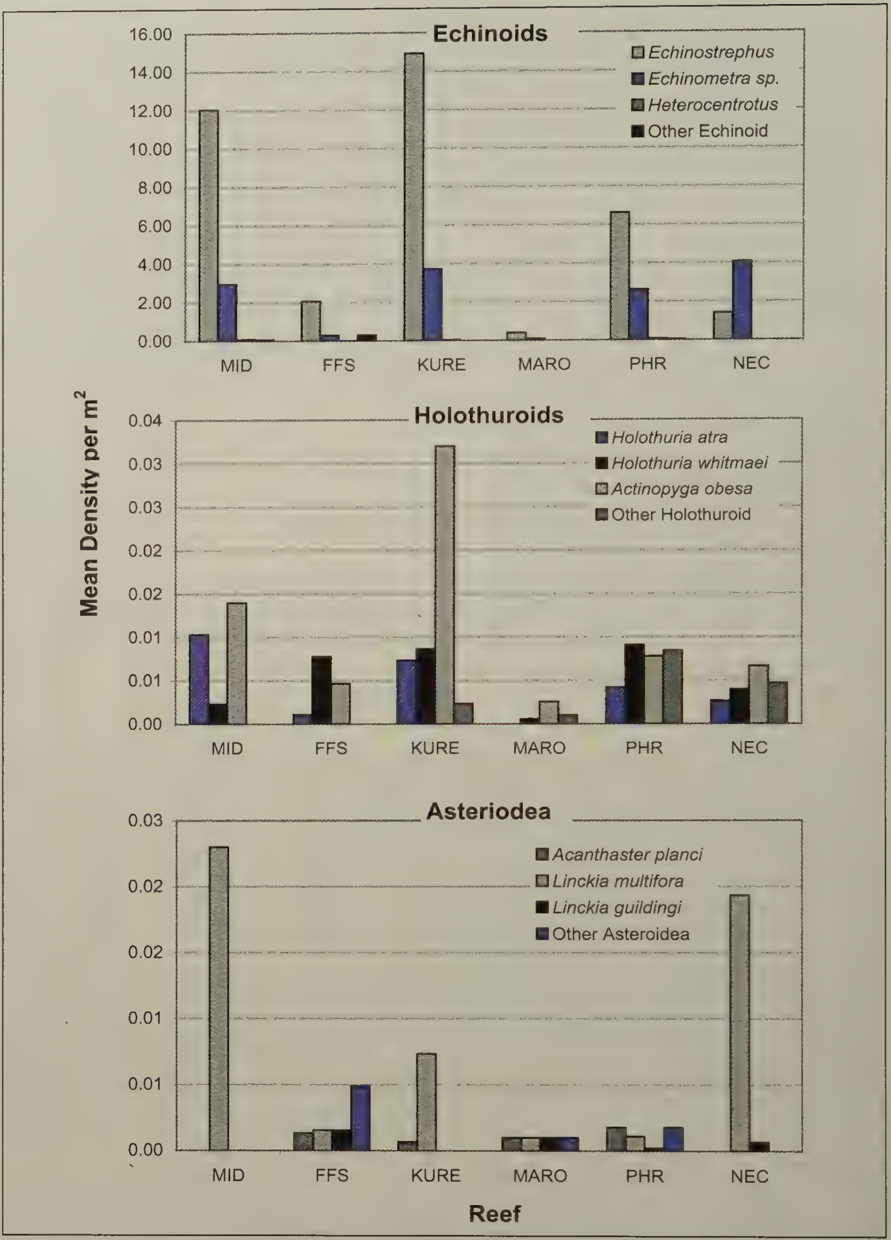


Figure 9.52. Mean density of echinoids, holothuroids and asteriods per m² in the NWHI. Source: PIFSC-CRED, unpub. data..

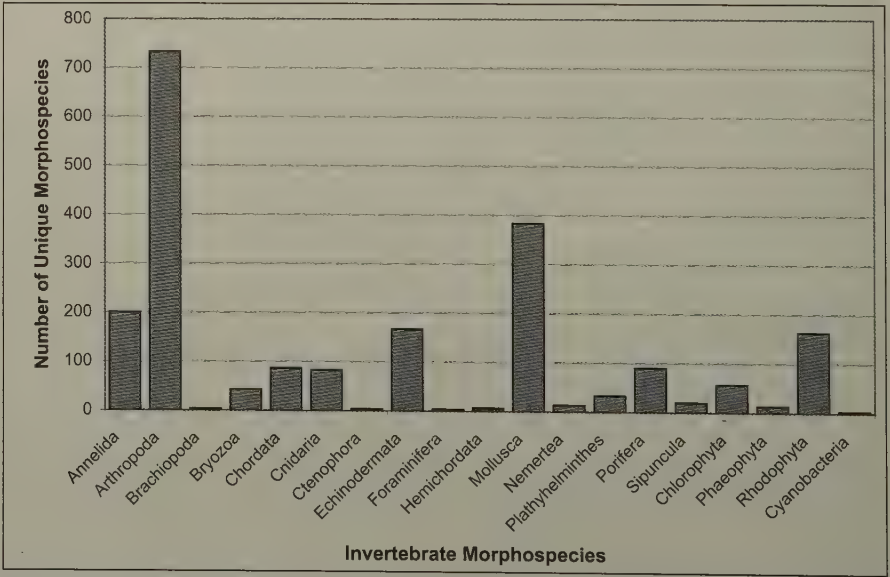


Figure 9.53. Number of unique morphospecies collected at French Frigate Shoals by phylum from CReefs cruise. Source: COML, unpub. data.

Though relatively high diversity was found for sponges, bryozoans, eulimid gastropods, hermit crabs, echinoderms and ascidians, other invertebrates, including corallimorph anemones, galatheid squat lobsters, porcellanid crabs, pea crabs, and coral barnacles, had strikingly low diversity or were absent. Interestingly, about one third of all invertebrate morphospecies collected were either found only once or found at only one site. A possible new ascidian of the family Mogulidae was collected, and a new species of coral that could not even be identified to family was found and photographed, though the permit did not allow sample collection. An estimated 48 new species records of opisthobranch molluscs for the French Frigate Shoals were collected, 27 of which appear to be new records for the NWHI. Of 366 algal specimens catalogued and preserved for molecular and taxonomic analysis, preliminary results suggest at least 160 unique morphospecies, with at least seven new records for algal species at French Frigate Shoals.

## SEABIRDS

Seabird colonies in the NWHI constitute one of the largest and most important assemblages of seabirds in the world, with approximately 14 million birds representing 21 species (Naughton and Flint, 2004). Greater than 95% of the world's Laysan (*Phoebastria immutabilis*) and Black-footed albatross (*P. nigripes*) nest in the NWHI (USFWS, 2005). For several other species such as Bonin petrel (*Pterodroma hypoleuca*), Christmas shearwater (*Puffinus nativitatis*), Tristram's storm-petrel (*Oceanodrama tristrami*) and Grey-backed tern (*Sterna lunata*), the NWHI supports colonies of global significance. The most numerous breeders are the Sooty Terns (*Sterna fuscata*), accounting for half of the total seabird numbers, followed by Laysan albatross with over 1 million breeders (Table 9.11; Figure 9.54). Five other species have annual breeding populations in excess of 100,000 birds.

The last complete inventory of breeding populations in the NWHI was done between 1979 and 1984. Population trends since then were derived from more intensive monitoring at three islands in the chain (French Frigate Shoals, Midway and Kure) and opportunistic sampling at other locations (Table 9.12). Population trends are stable or increasing for most species but there is concern for a few, especially the albatross. As part of North American Waterbird Conservation planning efforts, teams of ornithologists classified seabirds by levels of conservation concern using six ranking factors. Eleven of 21 species were ranked as either highly imperiled or of high conservation concern. When ranked regionally, Hawaiian seabird populations were healthier than conspecifics elsewhere; only six species were considered highly imperiled or of high conservation concern: Laysan, Black-footed and Short-tailed albatross, Christmas shearwater, Tristram storm-petrel and Blue noddy.

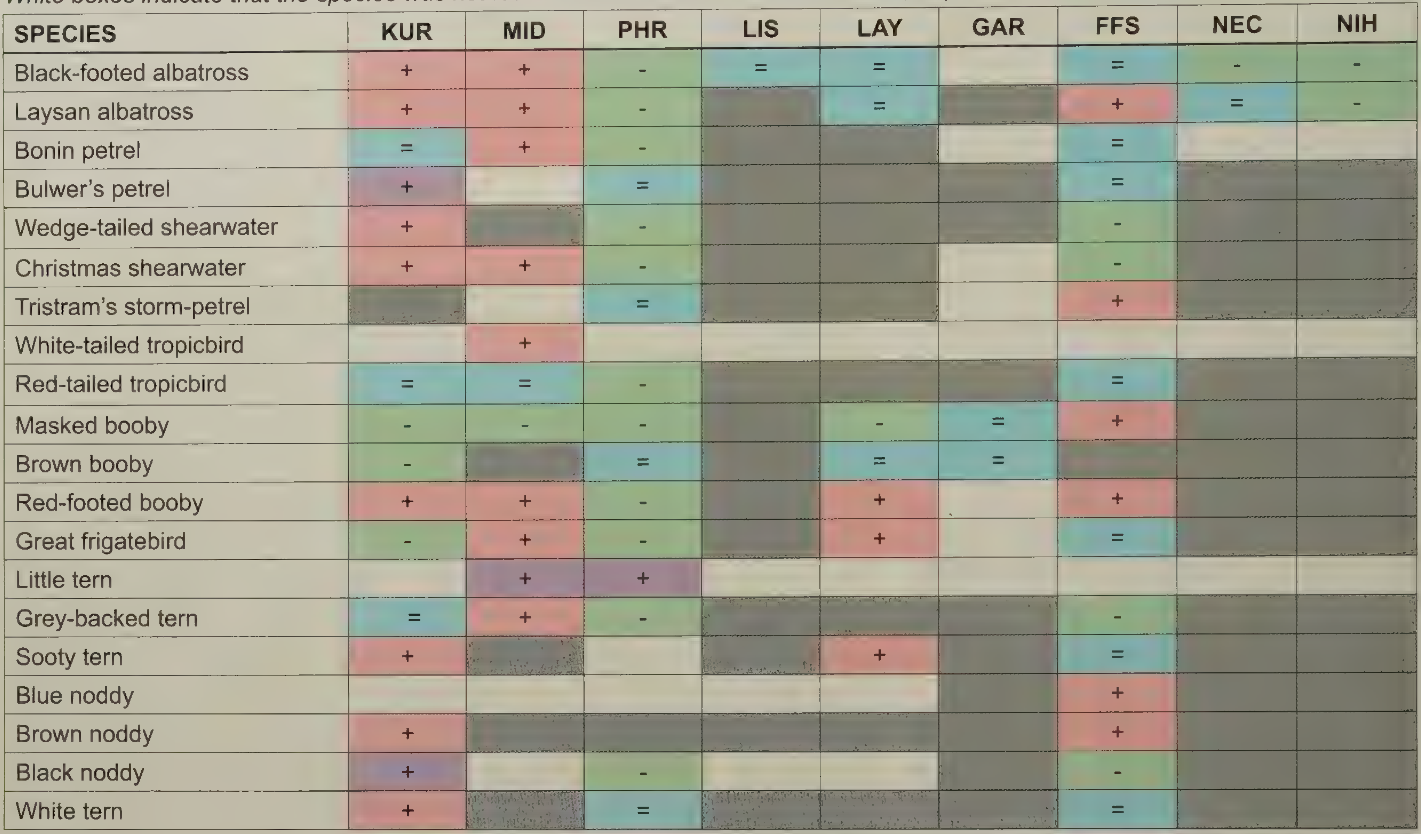
The greatest threats to seabirds in the NWHI are introduced mammals and other invasive species, fishery interactions, contaminants, oil pollution and climate changes with associated sea level rise. Over the past 20 years, active management for seabirds in the NWRs and State Seabird Sanctuary has included the eradication of black rats (*Rattus rattus*) at Midway Atoll and Pacific or Polynesian rats (*Rattus exulans*) at Kure Atoll; the eradication and control of invasive plants; coordination among NOAA Fisheries, the Western Pacific Fisheries Management Council, industry and conservation organizations to reduce fishing impacts; and the cleanup of contaminants and removal of obstructions at former military sites. The NWHI is unique in being one of the largest

*Table 9.11. Estimated number of breeding seabirds and percentage of total in the NWHI. Source: FWS, unpub. data.*

| SPECIES | NUMBER | PERCENTAGE |
|---|---|---|
| Sooty tern | 3,000,000 | 50.25 |
| Laysan albatross | 1,234,000 | 20.67 |
| Bonin petrel | 630,000 | 10.55 |
| Wedge-tailed shearwater | 450,000 | 7.54 |
| Bulwer's petrel | 180,000 | 3.02 |
| Brown noddy | 150,000 | 2.51 |
| Black-footed albatross | 111,800 | 1.87 |
| Gray-backed tern | 86,000 | 1.44 |
| Black noddy | 26,000 | 0.44 |
| White tern | 22,000 | 0.37 |
| Great frigatebird | 19,800 | 0.33 |
| Red-tailed tropicbird | 18,400 | 0.31 |
| Red-footed booby | 15,800 | 0.26 |
| Tristram's storm-petrel | 11,000 | 0.18 |
| Blue noddy | 7,000 | 0.12 |
| Christmas shearwater | 5,400 | 0.09 |
| Masked booby | 3,400 | 0.06 |
| Brown booby | 800 | 0.01 |
| White-tailed tropicbird | 8 | <0.01 |
| Little tern | <20 | <0.01 |
| **TOTAL** | **5,970,000** | **100.00** |

*Figure 9.54. Adult Laysan albatross* (Phoebastria immutabilis) *at Midway Atoll National Wildlife Refuge. Photo: A. Friedlander.*

*Table 9.12. Overview of seabird monitoring efforts and findings since the last assessment in the NWHI. Gray boxes indicate species and sites that have not been surveyed since 1984. Pink boxes indicate an apparent increase of greater than 25% since 1984 and green a greater than 25% apparent decrease. Blue indicates little change and purple represent new records for that species at that location. White boxes indicate that the species was not found at that location. Source: USFWS, unpub.data.*



| SPECIES | KUR | MID | PHR | LIS | LAY | GAR | FFS | NEC | NIH |
|---|---|---|---|---|---|---|---|---|---|
| Black-footed albatross | + | + | - | = | = |  | = | - | - |
| Laysan albatross | + | + | - | ▨ | = | ▨ | + | = | - |
| Bonin petrel | = | + | - | ▨ | ▨ |  | = |  |  |
| Bulwer's petrel | + |  | = | ▨ | ▨ | ▨ | = | ▨ | ▨ |
| Wedge-tailed shearwater | + | ▨ | - | ▨ | ▨ | ▨ | - | ▨ | ▨ |
| Christmas shearwater | + | + | - | ▨ | ▨ |  | - | ▨ | ▨ |
| Tristram's storm-petrel | ▨ |  | = | ▨ | ▨ |  | + | ▨ | ▨ |
| White-tailed tropicbird |  | + |  |  |  |  |  |  |  |
| Red-tailed tropicbird | = | = | - | ▨ | ▨ | ▨ | = | ▨ | ▨ |
| Masked booby | - | - | - | ▨ | - | = | + | ▨ | ▨ |
| Brown booby | - | ▨ | = | ▨ | = | = | ▨ | ▨ | ▨ |
| Red-footed booby | + | + | - | ▨ | + |  | + | ▨ | ▨ |
| Great frigatebird | - | + | - | ▨ | + |  | = | ▨ | ▨ |
| Little tern |  | + | + |  |  |  |  |  |  |
| Grey-backed tern | = | + | - | ▨ | ▨ | ▨ | - | ▨ | ▨ |
| Sooty tern | + | ▨ |  | ▨ | + | ▨ | = | ▨ | ▨ |
| Blue noddy |  |  |  |  |  | ▨ | + | ▨ | ▨ |
| Brown noddy | + | ▨ | ▨ | ▨ | ▨ | ▨ | + | ▨ | ▨ |
| Black noddy | + |  | - |  |  | ▨ | - | ▨ | ▨ |
| White tern | + | ▨ | = | ▨ | ▨ | ▨ | = | ▨ | ▨ |

marine protected areas in the world and one of only a few places that has received protection for nearly 100 years, since establishment of the Hawaiian Islands National Wildlife Refuge in 1909 for the express purpose of protecting seabirds. Early protection and active management has resulted in large, diverse and relatively intact seabird populations.

## MONK SEALS

The Hawaiian monk seal (*Monachus schauinslandi*) is the only endangered pinniped occurring entirely within U.S. waters. Its current population is estimated at 1,200 seals, a decrease of about 60% since the 1950s (Antonelis et al., 2006). Counts declined about 5% per year from 1985 to 1993, were relatively stable through 2000, and declined again in 2001. When compared historically, the monk seal beach count abundance index reached record lows in 2005 (Figure 9.55).

Population trends have been variable at the six main reproductive subpopulations in the NWHI (Baker and Thompson, 2006). In recent years overall pup production and juvenile survival have decreased at most sites (Figure 9.56). The largest subpopulation is at French Frigate Shoals where counts of non-pups have dropped by 60% since 1989, and the age distribution has become severely inverted due to high juvenile mortality over the last decade. Future abundance trends will likely depend upon whether predicted losses at French Frigate Shoals are countered by gains at other locations.

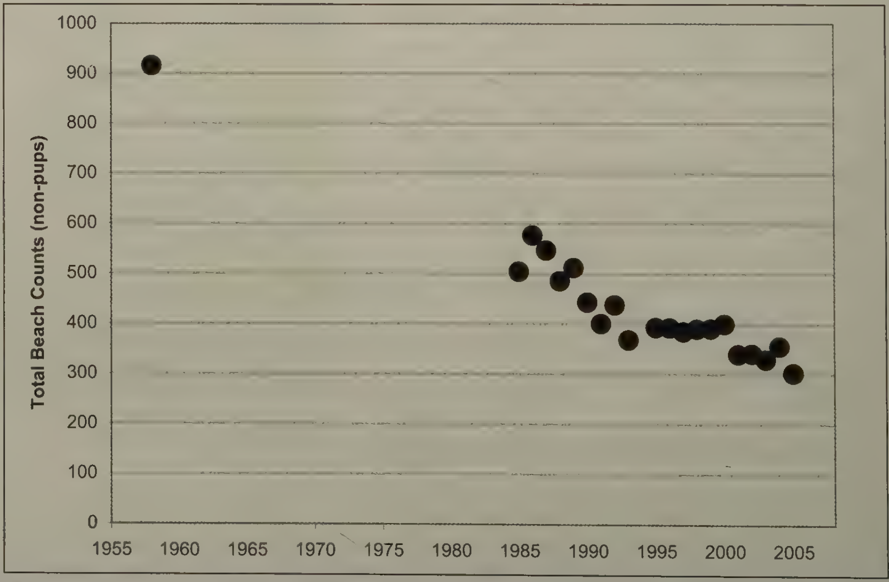


*Figure 9.55. Historical trend in beach counts (non-pups) of Hawaiian monk seals at the six main reproductive subpopulations. Source: Antonelis et al., 2006; updated by Baker, PIFSC.*

Monk seals occur throughout the Hawaiian Archipelago, and although most are found in the NWHI, a small but increasing number haul out and pup in the MHI. They commonly occur on isolated beaches for resting, molting, parturition and nursing offspring, but spend nearly two-thirds of their time in marine habitats. Monk seals are primarily benthic foragers (Goodman-Lowe, 1998), and will search for food in waters up to 500 m and over different substrates (Parrish et al., 2006). Food availability in their marine habitat seems to be a limiting factor to population growth in the NWHI, with the greatest impact of food limitation being on the survival of juvenile and yearling seals, age of sexual maturity and fecundity. This has possibly resulted from a downward trend in ocean productivity in the NWHI in the past decade associated with the Pacific Inter-Decadal Oscillation, coupled with the erosion and loss of important pupping habitats (French Frigate Shoals), and entanglement by marine debris (Antonelis et al., 2006).

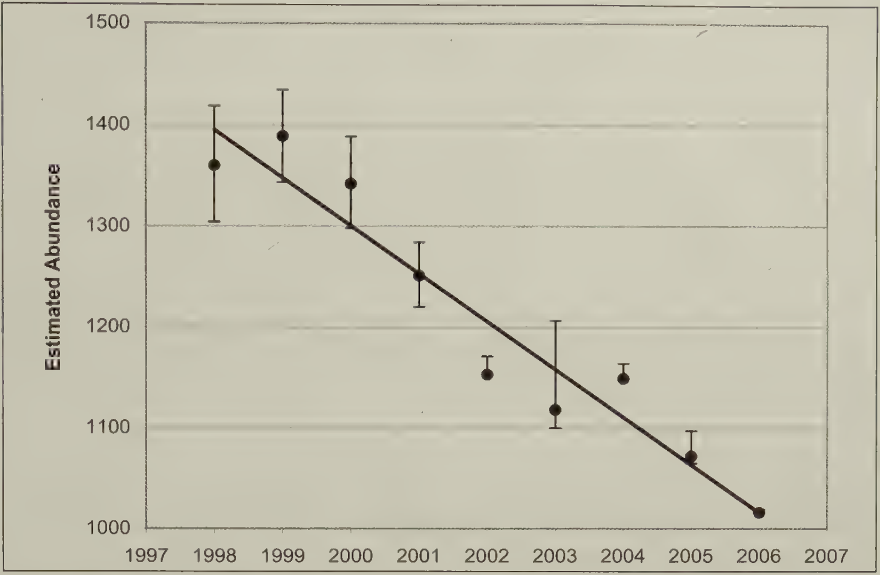


*Figure 9.56. Estimated abundance of monk seals at six major reefs in the NWHI. Fewer seals are located on smaller islands in the NWHI and MHI. Source: PIFSC.*

Past and present sources of anthropogenic and natural impacts to monk seals include: hunting during the 1880s; disturbance (e.g., active and post World War II military activities); entanglement in marine debris; direct fishery interactions prior to establishment of the 1991 Protected Species Zone in the NWHI; predation by sharks; aggression by adult male monk seals; and reduction of habitat and prey due to environmental change. Assessment and mitigation of factors limiting population growth are ongoing challenges and primary objectives of the monk seal recovery effort. The monk seal recovery plan may be found on the Internet at http://www.nmfs.noaa.gov/pr/pdfs/recovery/hawaiianmonkseal.pdf.

## TURTLES

The green turtle (*Chelonia mydas*) is the most abundant, large marine herbivore and has a circumtropical distribution with distinct regional population structures. Globally, the green turtle has been subject to a long history of human exploitation with some stocks now extinct and others in decline. The Hawaiian green turtle, or honu, stock comprises a single closed genetic stock that is endemic to the Hawaiian Archipelago (Bowen et al., 1992) with numerous distinct foraging grounds within the 2,200 km span of the Hawaiian Archipelago. From the mid-1800s until about 1974, the Hawaiian stock was subject to human exploitation such as turtle harvesting at foraging grounds, harvesting of nesters and eggs and nesting habitat destruction. Turtles found at Midway have a significantly slower somatic growth rate and older age of maturity than turtles from MHI (Balazs and Chaloupka, 2004).

The principal rookery for the Hawaiian green sea turtle is located on sand islands at French Frigate Shoals and accounts for more than 90% of all nesting within the Hawaiian Archipelago (Balazs and Chaloupka, 2006). The main rookery island at French Frigate Shoals is East Island where at least 50% of all French Frigate Shoals nesting occurs. Nesting females exhibit strong island fidelity, and the Hawaiian green sea turtle stock has been continuously monitored for several decades. Annual surveys of the number of female green turtles coming ashore to nest each night have been conducted at East Island since 1973.

Green sea turtles in U.S. waters have been protected under the Federal Endangered Species Act since 1978. It was recently estimated that the Hawaiian green turtle stock was about 20% of pre-exploitation biomass when monitoring and protection began in the 1970s. The stock is estimated to be now about 83% of pre-exploitation biomass with an intrinsic growth rate of approximately 5.4% (Chaloupka and Balazs, 2006).

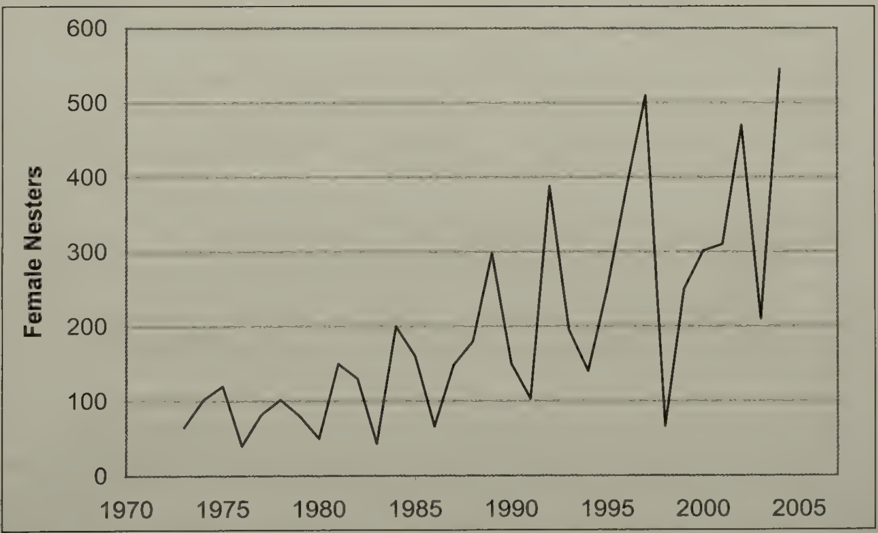


*Figure 9.57. Nester abundance shown as the number of female green sea turtles nesting each year at East Island, French Frigate Shoals from 1973 to 2004. Source: Balazs and Chaloupka, 2006.*

Long-term trends based on a population model for the East Island nester abundance illustrates two main features: a dramatic increase in abundance over the 30-year study and substantial fluctuations in the number of annual nesters (Figure 9.57). Such fluctuations are characteristic of green turtle nesting populations and reflect a variable proportion of females in the population that breed each year in response to spatially correlated ocean-climate variability. The Hawaiian green sea turtle stock is clearly recovering after more than 25 years of protection of their nesting and foraging habitats in the Hawaiian Archipelago.

## CURRENT CONSERVATION MANAGEMENT ACTIVITIES

Management of the PMNM is the responsibility of three co-trustee agencies: the state of Hawaii; the United States Department of the Interior, USFWS; and the Department of Commerce, NOAA. The co-trustees are committed to preserving the ecological integrity of the monument and perpetuation of NWHI ecosystems, Native Hawaiian culture and other historic resources. NOAA and USFWS promulgated final regulations for the monument under 50 CFR Part 404 on August 19, 2006. These regulations codify the scope and purpose, boundary, definitions, prohibitions and regulated activities for managing the monument. In addition, the co-trustees developed and signed a Memorandum of Agreement (MOA) on December 8, 2006, to establish roles and responsibilities, and coordination bodies and mechanisms for managing the monument.

In addition to the development of a management plan, the co-trustees are also developing a research plan that will provide the direction for research in the NWHI over the next several years. This plan will be based on a draft Hawaiian archipelago research plan that is currently being finalized, results of a NWHI research symposium held in 2004, and inputs from a workshop to gather research themes held in 2002 as a part of a NWHI Coral Reef Ecosystem Reserve effort. This plan will complement the objectives outlined in the management plan.

## OVERALL CONCLUSIONS AND RECOMMENDATIONS

The Papahanaumokuakea Marine National Monument (PMNM) is the largest fully protected marine conservation area in the world, and the unique predator-dominated trophic structure, the dominance by large numbers of endemic species, and the occurrence of a number of threatened and endangered species make it an important global biodiversity hotspot. Large numbers of seabirds are crucial components of the nutrient cycle in this ecosystem and suggest a strong connectivity between land and sea in this largely untouched environment. The NWHI are one of the few regions on earth where monitoring and research activities can be conducted in virtual absence of human presence. By comparison, most reef systems in the coastal regions of the world are adjacent to human population centers, where vessel traffic, overharvesting, sedimentation, habitat destruction and other human actions have altered the terrestrial and adjacent marine environments. The NWHI allow us to see what subtropical reefs looked like in the past and provide an opportunity to examine what could occur if larger more effective no-take marine reserves were to be established elsewhere.

Large unfished reference areas are extremely rare and valuable tools that can be used to establish baseline conditions and determine the current status of exploited areas using a space-for-time substitution. The NWHI provide a unique opportunity to compare the health of a nearly pristine ecosystem with the ecosystem of the human-impacted MHI (Friedlander and DeMartini, 2002; Sladek Nowlis et al., in review). Results have clearly shown that the coral reef ecosystem of the MHI is in very poor condition compared with the NWHI, and even small protected areas in the MHI do not adequately protect the full complement of species or interactions found in the NWHI (Friedlander et al., 2007). The limited deepwater bottomfish fishery in the NWHI is scheduled to close in 2011, and until that time, monitoring of this fishery can provide crucial information that can be applied to management across the archipelago.

Climate change may have a large impact on coral reef ecosystems and their management in the years to come. The PMNM provides a unique opportunity to examine the effects of climate change on a nearly intact large-scale marine ecosystem without direct and localized anthropogenic influences (Keller et al., in press). Sea level rise, coral bleaching, disease and ocean acidification are just a few of the potential impacts of climate change on coral reefs, and by understanding resilience and resistance to these stressors in a "natural" ecosystem, we can apply these findings to better inform decision making and management actions in the Hawaiian Archipelago and other coral reef ecosystems worldwide, where anthropogenic stressors are significantly greater.

An important future direction for biological research in the NWHI will be advancing our understanding of metapopulation dynamics and connectivity, especially for coral reef species. Demographic connectivity of coral reef organisms is typically on the order of 10s to 100s of km (Palumbi, 2004; Cowen et al., 2006), so many of the reefs in the NWHI may be isolated and therefore susceptible to localized extinction. Greater knowledge of recruitment variability, current patterns, larval retention, and genetic connectivity will be required to better understand the dynamics of population replenishment in this region.

By developing strong and lasting joint management initiatives and the framework for continued cooperation among the co-trustees and other partners, the PMNM can implement comprehensive and integrated management that is ecosystem-based and addresses the management needs of this valuable and irreplaceable ecosystem well into the future. Research results and management outcomes from the PMNM can also be used to inform management decisions throughout the Hawaiian Archipelago and coral reef ecosystems elsewhere.

An important step in this direction is the *Hawaiian Archipelago Marine Ecosystem Research Plan*, which strives to understand the archipelago's marine physical and biological environments, their dynamics and their interactions with human beings as a single connected system leading toward improved resource management. This ten-year, multi-agency, collaborative program is proposed to advance ecosystem science and resource management throughout the Hawaiian Archipelago. Few regions on the planet have the isolation, spatial structure and research history that are needed to evaluate ecosystem dynamics and function at this scale. This collaborative plan is designed to advance ecosystem science, develop new technologies and assist society in making the most of its resources while preserving them for future generations.

The millions of pounds of marine debris that have accumulated in the NWHI illustrate the global scale of the impacts that are occurring in the NWHI and constitute an urgent call for international cooperation on this and other large-scale stressors such as climate change. Due to the proliferation of distant-water fishing fleets, remote places like the NWHI are increasingly susceptible to poaching, and concerted efforts requiring improved surveillance technologies will be necessary to combat this threat. Increased threats from disease, ocean acidification, sea level rise and bleaching associated with climate change, are the most significant long-term threats to the NWHI.

Remote, uninhabited, and relatively pristine in comparison to other marine ecosystems of the world, the NWHI serve as a key sentinel for monitoring and deciphering short-term and long-term responses to local, regional, and global environmental and anthropogenic stressors. Ongoing research, monitoring, habitat restoration and conservation management of the insular and marine ecosystems in the NWHI will continue to provide significant insights that will benefit management interventions not only for the NWHI, but for insular and marine ecosystems around the world. Globally, the NWHI represent a natural and cultural treasure of high scientific, conservation and aesthetic value, and the wise stewardship of this unique ecosystem is the responsibility of us all.

## REFERENCES

Aeby, G.S. 2005. Outbreak of coral disease in the Northwestern Hawaiian Islands. Coral Reefs 24: 481.

Aeby, G.S. 2006. Baseline levels of coral disease in the Northwestern Hawaiian Islands. Atoll Res. Bull. 543: 471-488.

Aeby, G.S. 2007. First record of coralline lethal orange disease (CLOD) in the Northwestern Hawaiian Islands. Coral Reefs 26(2): 385.

Allen, G.R. 2002. Indo-Pacific coral-reef fishes as indicators of conservation hotspots. pp. 921-926. In: M.K. Moosa, S. Soemodihardjo, A. Soegiarto, K. Romimohtarto, A. Nontji, Soekarno and Suharsono (ed.). Proceedings of the 9th International Coral Reef Symposium, Vol. 2. Bali, Indonesia. 580 pp.

Andrews, K.R., L. Karczmarski, W.W.L. Au, S.H. Rickards, C.A. Vanderlip, and R.J. Toonen. 2006. Patterns of genetic diversity of the Hawaiian spinner dolphin (*Stenella longirostris*). Atoll Res. Bull. 543: 65-73.

Antonelis, G.A., J.D. Baker, T.C. Johanos, R.C. Braun, and A.L. Harting. 2006. Hawaiian Monk seal (*Monachus schauinslandi*): status and conservation issues. Atoll Res. Bull. 543: 75-101.

Baker, J.D. and P.M. Thompson. 2006. Temporal and spatial variation in age-specific survival rates for a long-lived mammal, the Hawaiian monk seal. Proc. R. Soc., B 274: 407-415.

Balazs, G.H., and M. Chaloupka. 2004. Spatial and temporal variability in somatic growth of green sea turtles (*Chelonia mydas*) resident in the Hawaiian Archipelago. Mar. Biol. 145: 1043-1059.

Balazs, G.H. and M. Chaloupka. 2006. Recovery trend over 32 years at the Hawaiian green turtle rookery of French Frigate Shoals. Atoll Res. Bull. 543: 147-158.

Bird, C.E., B.S. Holland, B.W. Bowen, and R.J. Toonen. 2007. Contrasting population structure in three endemic Hawaiian limpets (*Cellana* spp.) with similar life histories. Mol. Ecol. 16: 3173-3187.

Boland, R., B. Zgliczynski, J. Asher, A. Hall, K. Hogrefe, and M. Timmers. 2006. Dynamics of debris densities and removal at Northwestern Hawaiian Islands coral reefs. Atoll Res. Bull. 543: 461-470.

Bowen, B.W., A.B. Meylan, J.R. Ross, C.J. Limpus, G.H. Balaz, and J.C. Avise. 1992. Global population structure and natural history of the green turtle (*Chelonia mydas*) in terms of matriarchal phylogeny. Evolution 46: 865-881.

Bromirski, P.D., D.R. Cayan, and R.E. Flick. 2005. Wave spectral energy variability in the northeast Pacific. J. Geophys. Res. 110: C03005, doi:10.1029/2004JC002398.

Caruso, S.J. and S. Businger. 2006. Subtropical cyclogenesis over the Central North Pacific. Wea. Forecasting 21(2): 193–205.

Chaloupka M. and G. Balazs. 2007. Using Bayesian state-space modelling to assess the recovery and harvest potential of the Hawaiian green sea turtle stock. Ecol. Model. 205: 93–109.

Cowen, R.K, C.B. Paris, and A. Srinivasan. 2006. Scaling of Connectivity in Marine Populations. Science 311(5760): 522-527.

Craig, M.T., J.A. Eble, D.R. Robertson, and B.W. Bowen. 2007. High genetic connectivity across the Indian and Pacific Oceans in the reef fish *Myripristis berndti* (Holocentridae). Mar. Ecol. Prog. Ser. 334: 245-254.

Dameron, O.J., M. Parke, M.A. Albins, and R. Brainard. 2007. Marine debris accumulation in the Northwestern Hawaiian Islands: an examination of rates and processes. Mar. Poll. Bull. 54(4): 423-433.

Dana, J.D. 1846. Zoophytes. United States Exploring Expedition: during the years 1838, 1839, 1840, 1841, 1842, under the command of Charles Wilkes, U.S.N., Vol. 7. Sherman Printer. Philadelphia, PA. 752 pp.

Dana, T.F. 1971. On the reef corals of the world's most northern atoll (Kure: Hawaiian Archipelago). Pac. Sci. 25:80-87.

DeMartini, E.E. 2004. Habitat and endemism of recruits to shallow reef fish populations: selection criteria for no-take MPAs in the NWHI Coral Reef Ecosystem Reserve. Bull. Mar. Sci. 14: 185–205.

DeMartini E.E., F.A. Parrish, and R.C. Boland. 2002. Comprehensive evaluation of shallow reef fish populations at French Frigate Shoals and Midway Atoll, Northwestern Hawaiian Islands (1992/93, 1995–2000). NOAA Technical Memorandum NMFS SWFSC 347. Honolulu, HI. 75 pp.

DeMartini E.E., and A.M. Friedlander. 2004. Spatial patterns of endemism in shallow reef fish populations of the Northwestern Hawaiian Islands. Mar. Ecol. Prog. Ser. 271: 1-296.

DeMartini, E.E., A.M. Friedlander, and S. Holzwarth. 2005. Size at sex change in protogynous labroids, prey size distributions, and apex predator densities at NW Hawaiian atolls. Mar. Ecol. Prog. Ser. 297: 259-271.

DeMartini, E.E. and A.M. Friedlander. 2006. Predation, endemism, and related processes structuring shallow-water reef fish assemblages of the Northwestern Hawaiian Islands. Atoll Res. Bull. 543: 237-256.

Donohue, M., R. Brainard, M. Parke, and D. Foley. 2000. Mitigation of environmental impacts of derelict fishing gear through debris removal and environmental monitoring. pp. 58-78. In: Proceedings from the 4th International Marine Debris Conference on Derelict Fishing Gear and the Marine Environment. Honolulu, HI. 217 pp.

Ehler, R. 2004. Socioeconomic assessment of commercial bottomfishing in the Northwestern Hawaiian Islands. Report to NOAA NOS National Marine Sanctuary Program. 46 pp.

Fenner, D. 2005. Corals of Hawaii. Mutual Publishing. Honolulu, HI. 143 pp.

Firing. J. and R.E. Brainard. 2006. Ten years of shipboard ADCP measurements along the Northwestern Hawaiian Islands. Atoll Res. Bull. 543: 347-363

Friedlander, A.M. and E.E. DeMartini. 2002. Contrasts in density, size, and biomass of reef fishes between the Northwestern and the main Hawaiian Islands: the effects of fishing down apex predators. Mar. Ecol. Prog. Ser. 230: 253-264.

Friedlander, A.M., J.D. Parrish, and R.C. DeFelice. 2002. Ecology of the introduced snapper *Lutjanus kasmira* (Forsskal) in the reef fish assemblage of a Hawaiian Bay. J. Fish. Biol. 60: 28-48.

Friedlander, A., G. Aeby, R. Brainard, A. Clark, E. DeMartini, S. Godwin, J. Kenyon, R. Kosaki, J. Maragos, and P. Vroom. 2005. The State of the Coral Reef Ecosystem of the Northwestern Hawaiian Islands. pp. 270-311. In: J.E. Waddell (ed.). The State of Coral Reef Ecosystems of the United States and Pacific Freely Associated States: 2005. NOAA Technical Memorandum NOS NCCOS 11. Silver Spring, MD. 522 pp.

Friedlander, A.M., E.E. DeMartini, and L. Wedding. In preparation. Habitat affinities and biogeographic patterns of coral reef fishes in a large marine reserve. J. Biogeogr.

Finkelstein, M.E., K.A. Grasman, D.A. Croll, B.R. Tershy, B.S. Keitt, W.M. Jarman, and D.R. Smith. 2007. Contaminant-associated alteration of immune function in black-footed albatrosses (*Phoebastria nigripes*), a North Pacific predator. Environ. Toxicol. Chem. 26(9): 1896-1903.

Godwin, L.S., K.S. Rodgers, and P.L. Jokiel. 2006. Reducing Potential Impact of Invasive Marine Species in the Northwestern Hawaiian Islands Marine National Monument. Report submitted to the Northwestern Hawaiian Islands Marine National Monument for research conducted under DOI, NOAA, National Ocean Service MOA 2005-008/6882 Amendment No. 001. 66 pp. http://cramp.wcc.hawaii.edu/CRAMP_Information/publications.htm.

Goodman-Lowe, G.D. 1998. Diet of the Hawaiian monk seal (*Monachus schauinslandi*) from the Northwestern Hawaiian Islands during 1991-1994. Mar. Biol. 132: 535-546.

Graham, N.E. and H.F. Diaz. 2001. Evidence for Intensification of North Pacific Winter Cyclones since 1948. Bull. Am. Meteorol. Soc. 82(9).

Grigg, R.W., J. Polovina, A. Friedlander, and S. Rohman. In press. Biology of the coral reefs in the Northwestern Hawaiian Islands. pp. 573-594. In: B. Riegl and R.E. Dodge (eds.). Coral Reefs of the USA. Coral Reefs of the World, Volume 1. Springer. 806 pp.

Grigg, R.W. 1981. Acropora in Hawaii. Part II. Zoogeography. Pac. Sci. 15: 15-24.

Grigg, R.W. 1988. Paleoceanography of coral reefs in the Hawaiian-Emperor chain. Science 240(4860): 1737-1742.

Hoegh-Guldberg, O. 1999. Climate change, coral bleaching and the future of the world's coral reefs. Mar. Freshw. Res. 50(8): 839-866.

Hoegh-Guldberg, O. 2004. Coral reefs and projections of future change. pp. 463-484. In: E. Rosenberg and Y. Loya (eds.). Coral Health and Disease. Springer. Berlin, Heidelberg, New York. 488 pp.

Hoeke R., R. Brainard, R. Moffitt, and J. Kenyon. 2006. Oceanographic conditions implicated in the 2002 Northwestern Hawaiian Islands bleaching event. pp. 718-723. In: Y. Suzuki, T. Nakamori, M. Hidaka, H. Kayanne, B.E. Casareto, K. Nadaoka, H. Yamano, and M. Tsuchiya (eds.). Proceedings of the 10th International Coral Reef Symposium. Okinawa, Japan. 1950 pp.

Holland B., M. Dawson, G. Crow, and D. Hofmann. 2004. Global phylogeography of *Cassiopea* (Scyphozoa: Rhizostomeae): molecular evidence for cryptic species and multiple invasions of the Hawaiian Islands. Mar. Biol. 145:1119-1128.

Hughes, T.P., A.H. Baird, D.R. Bellwood, M. Card, S.R. Connolly, C. Folke, R. Grosberg, O. Hoegh-Guldberg, J.B.C. Jackson, J. Kleypas, J.M. Lough, P. Marshall, M. Nystrom, S.R. Palumbi, J.M. Pandolfi, B. Rosen, and J. Roughgarden. 2003. Climate change, human impacts, and the resilience of coral reefs. Science 301(5635): 929-933.

Intergovernmental Panel on Climate Change (IPCC). 2007. Climate Change 2007: The Physical Science Basis, Summary for Policy Makers, Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.

Jokiel, P.L. 1987. Ecology, Biogeography and Evolution of Coral in Hawaii. Trends Ecol. Evol. 2(7): 179-182.

Jokiel, P.L. and K.S. Rodgers. 2007. Ranking coral ecosystem "health" and "value" for the islands of the Hawaiian Archipelago. Pac. Conserv. Biol. 13: 60-68.

Kawamoto, K. and D. Gonzales. 2005. Summary of bottomfish landings in the Hawaiian Island Archipelago, 1996-2004. NOAA NMFS Pacific Islands Fisheries Science Center Internal Report IR-05-023. 9 pp.

Kay, E.A. and S.R. Palumbi. 1987. Endemism and evolution in Hawaiian marine invertebrates. Trends Ecol. Evol. 2(7): 183-186.

Keller, B.D., S. Airame, B. Causey, A. Friedlander, D. Gleason, R. Grober-Dunsmore, J. Johnson, E. McLeod, S.L. Miller, R. Steneck, and C. Woodley. In press. Marine protected areas. In: Preliminary review of adaptation options for climate-sensitive ecosystems and resources. Report by U.S. Climate Change Science Program and the Subcommittee on Global Change Resources. Washington, DC.

Kelley, C. and R. Moffit. 2004. The impacts of bottomfishing on the Raita and west St. Rogatien reserve preservation areas in the northwestern Hawaiian Islands Coral Reef Ecosystem Reserve. Final Report to the Northwestern Hawaiian Islands Coral Reef Ecosystem Reserve. 49 pp.

Kenyon, J.C. and R.E. Brainard. 2006. Second recorded episode of mass coral bleaching in the Northwestern Hawaiian Islands. Atoll Res. Bull. 543: 505-523.

Kenyon, J.C., G.S. Aeby, R.E. Brainard, J.D. Chojnacki, M.J. Dunlap, and C.B. Wilkinson. 2006a. Mass coral bleaching on high-latitude reefs in the Hawaiian Archipelago. pp. 631-643. In: Y. Suzuki, T. Nakamori, M. Hidaka, H. Kayanne, B.E. Casareto, K. Nadaoka, H. Yamano, and M. Tsuchiya (eds.). Proceedings of the 10th International Coral Reef Symposium. Okinawa, Japan. 1950 pp.

Kenyon, J.C., R.E. Brainard, R.K. Hoeke, F.A. Parrish, and C.B. Wilkinson. 2006b. Towed-diver surveys, a method for mesoscale spatial assessment of benthic reef habitat: a case study at Midway Atoll in the Hawaiian Archipelago. Coast. Manage. 34(3): 339-349.

Kenyon, J.C., P.S. Vroom, K.N. Page, M.D. Dunlap, C.B. Wilkinson, and G.S. Aeby. 2006c. Community structure of hermatypic corals at French Frigate Shoals in the Northwestern Hawaiian Islands: capacity for resistance and resilience to selective stressors. Pac. Sci. 60(2): 151-173.

Kenyon, J.C., M.J. Dunlap, C.B. Wilkinson, K.N. Page, P.S. Vroom, and G.S. Aeby. 2007. Community structure of hermatypic corals at Pearl and Hermes Atoll, Northwestern Hawaiian Islands: unique conservation challenges within the Hawaiian Archipelago. Atoll Res. Bull. 549: 1-23.

Kleypas, J.A., R.W. Buddemeier, D. Archer, J. Gattuso, C. Langdon, and B.N. Opdyke. 1999. Geochemical consequences of increased atmospheric carbon dioxide on coral reefs. Science 284(5411): 118-120.

Kleypas, J.A., R.A. Feely, V.J. Fabry, C. Langdon, C.L. Sabine, and L.L. Robbins. 2005. Impacts of Ocean Acidification on Coral Reefs and Other Marine Calcifiers: A Guide for Future Research. Report of a workshop sponsored by National Science Foundation, NOAA, and U.S. Geological Society. St. Petersburg, FL. 88 pp. http://www.ucar.edu/communications/Final_acidification.pdf

Kohler, E. and S.M. Gill. 2006. Coral Point Count with Excel extensions (CPCe): A Visual Basic program for the determination of coral and substrate coverage using random point count methodology. Comput. Geosci. 32: 1259-1269.

Leonard, C.L., R.R. Bidigare, M.P. Seki, and J.J. Polovina. 2001. Interannual mesoscale physical and biological variability in the North Pacific Central Gyre. Progr. Oceanogr. 49(1-4): 227-244.

Little, A., J. van Oppen, and B. Willis. 2004. Flexibility in algal endosymbioses shapes growth in reef corals. Science 304(5676): 1492-1494.

Littler, M.M. and D.S. Littler. 1997. Disease-induced mass mortality of crustose coralline algae on coral reefs provides rationale for the conservation of herbivorous fish stocks. pp. 719-724. In: H.A. Lessios and I.G. Macintyre (eds.). Proceedings of the 8th International Coral Reef Symposium, Vol. 1. Panama City, Panama. 1040 pp.

McPhaden, M., A. Busalacchi, R. Cheney, J. Donguy, K. Gage, D. Halpern, M. Ji, P. Julian, G. Meyers, G. Mitchum, P. Niiler, J. Picaut, R. Reynolds, N. Smith, and K. Takeuchi. 1998. The Tropical Ocean-Global Atmosphere Observing System: A decade of progress. J. Geophys. Res. 103(14): 169-240.

Maragos, J.E., and P.L. Jokiel. 1986. Reef corals of Johnston Atoll: One of the world's most isolated reefs. Coral Reefs 4: 141-150.
Miller, J.E., R.K. Hoeke, T.B. Appelgate, P.J. Johnson, J.R. Smith, and S. Bevaqua. 2003. Bathymetric Atlas of the Northwestern Hawaiian Islands, Draft- February 2004. NOAA. 65 pp.

Maragos J.E., D.C. Potts, G.S. Aeby, D. Gulko, J.C. Kenyon, D. Siciliano, and D. VanRavenswaay. 2004. 2000-2002 Rapid Ecological Assessments of corals (Anthozoa) on shallow reefs of the Northwestern Hawaiian Islands. Part 1: species and distribution. Pac. Sci. 58(2): 211-230.

Morishige, C., M. Donohue, E. Flint, C. Swenson, and C. Woolaway. 2007. Factors affecting marine debris deposition at French Frigate Shoals, Northwestern Hawaiian Islands Marine National Monument, 1990-2006. Mar. Poll. Bull. 54: 1162–1169.

Muscatine, L. and J.W. Porter. 1977. Reef corals: mutualistic symbioses adapted to nutrient-poor environments. BioScience 27: 454-460.

Meyer, C.G., K.N. Holland, and Y.P. Papastamatiou. 2007b. Seasonal and diel movements of giant trevally (*Caranx ignobilis*) at remote Hawaiian atolls: implications for the design of Marine Protected Areas. Mar. Ecol. Prog. Ser. 333: 13-25.

Meyer, C.G., Y.P. Papastamatiou, and K.N. Holland. 2007a. Seasonal, diel and tidal movements of green jobfish (*Aprion virescens*, Lutjanidae) at remote Hawaiian atolls: Implications for Marine Protected Area design. Mar. Biol. 151: 2133-2143.

Myers, R.A. and B. Worm. 2003. Rapid worldwide depletion of predatory fish communities. Nature 423: 280-283.

Myers, R.A. and B. Worm. 2005. Extinction, survival or recovery of large predatory fishes. Phil. Trans. R. Soc. Britain 360: 13-20.

Naughton, M. and E. Flint. 2004. Populations and conservation status of seabirds in the Northwestern Hawaiian Islands. Abstract presented at the 3rd Northwestern Hawaiian Islands Science Symposium. Honolulu, HI.

National Oceanic and Atmospheric Administration (NOAA). 2003. Atlas of the Shallow-water Benthic Habitats of the Northwestern Hawaiian Islands (Draft). Center for Coastal Monitoring and Assessment. Silver Spring, MD. 160 pp. http://ccma.nos.noaa.gov/ecosystems/coralreef/nwhi/welcome.html

Okihiro, M.S. 1988. Chromatophoromas in two species of Hawaiian butterflyfish, *Chaetodon multicinctus* and *C. miliaris*. Vet. Pathol. 25: 422-431.

Orr, J.C., V.J. Fabry, O. Aumont, L. Bopp, S.C. Doney, R.A. Feely, A. Gnanadesikan, N. Gruber, A. Ishida, F. Joss, R.M. Key, K. Lindsay, E. Maier-Reimer, R. Matear, P. Monfray, A. Mouchet, R.G. Najjar, G. Plattner, K.B. Rodgers, C.L. Sabine, J.L. Sarmiento, R. Schlitzer, R.D. Slater, I.J. Totterdell,W. Weirig, Y. Yamanaka, and A. Yool. 2005. Anthropogenic Ocean Acidification over the Twenty-First Century and its Impact on Calcifying Organisms. Nature 437: 681-686.

Page, K.N. 2006. Factors influencing benthic distributional patterns in a near-pristine coral reef ecosystem: Pearl and Hermes Atoll. M.S. Thesis. University of Hawaii.

Palumbi, S.R. 2004. Marine reserves and ocean neighborhoods: the spatial scale of marine populations and their management. Annu. Rev. Environ. Res. 29: 31-68.

Parrish, F.A., M.P. Craig, T.J. Ragen, G.J. Marshall, and B.M. Buhleier. 2000. Identifying diurnal foraging habitat of endangered Hawaiian monk seals using a seal-mounted video camera. Mar. Mamm. Sci. 16: 392-412.

Parrish, F.A., K. Abernathy, G.J. Marshall, and B.M. Buhleier. 2002. Hawaiian monk seals (*Monachus schauinslandi*) foraging in deep-water coral beds. Mar. Mamm. Sci. 18: 244-258.

Parrish, F.A., G.J. Marshall, C.L. Littnan, M. Heithaus, S. Canja, B.L. Becker, R.C. Braun, and G.A. Antonelis. 2005. Foraging of juvenile monk seals at French Frigate Shoals, Hawaii. Mar. Mamm. Sci. 21(1): 93-107.

Parrish, F.A. and K. Abernathy. 2006. Movements of monk seals relative to ecological depth zones in the lower Northwestern Hawaiian Islands. Atoll Res. Bull. 543: 115-130.

Philander, S.G. 1990. El Niño, La Niña and the Southern Oscillation. Academic Press. San Diego, CA. 293 pp.

Polovina, J.J., G.T. Mitchum, N.E. Graham, M.P. Craig, E.E. DeMartini, and E.N. Flint. 1994. Physical and biological consequences of a climate event in the central North Pacific. Fish. Oceanogr. 3: 15–21.

Polovina, J.J., E. Howell, D.R. Kobayashi, and M.P. Seki. 2001. The transition zone chlorophyll front, a dynamic global feature defining migration and forage habitat for marine resources. Prog. Oceanogr. 49(1-4): 469-483.

Preskitt, L.B., P.S. Vroom, and C.M. Smith. 2004. A rapid ecological assessment (REA) quantitative survey method for benthic algae using photo quadrats with SCUBA. Pac. Sci. 58: 201-209.

Randall, J.E. 1987. Introduction of marine fishes to the Hawaiian Islands. Bull. Mar. Sci. 41: 490-502.

Randall, J.E. 2007. Reef and shore fishes of the Hawaiian Islands. Sea Grant Program, University of Hawaii. Honolulu, HI. 560 pp.

Randall, J.E., J.L. Earle, R.L. Pyle, J.D. Parrish, and T. Hayes. 1993. Annotated checklist of the fishes of Midway Atoll, Northwestern Hawaiian Islands. Pac. Sci. 47: 356-400.

Rivera, M., C. Kelley, and G. Roderick. 2004. Subtle population genetic structure in the Hawaiian Grouper, *Epinephelus quernus* as revealed by mitochondrial DNA analyses. Biol. J. Linn. Soc. 81: 449-468.

Roberts, C.M., C.J. McClean, J.E.N. Veron, J.P. Hawkins, G.R. Allen, D.E. McAllister, C.G. Mittermeier, F.W. Schueler, M. Spalding, F. Wells, C. Vynne, and T.B. Werner. 2002. Marine biodiversity hotspots and conservation priorities for tropical reefs. Science 295(5558): 1280-1284.

Rocha, L.A., M.T. Craig, and B.W. Bowen. 2007. Phylogeography and the conservation of coral reef fishes. Coral Reefs 26(3): 501-512.

Roemmich, D. 1984. Indirect sensing of equatorial currents by means of island pressure measurements. J. Phys. Oceanogr. 14: 1458-1469.

Rooney, J., P. Wessel, R. Hoeke, J. Weiss, J. Baker, F. Parrish, C. Fletcher, J. Chojnacki, M.O. Garcia, and P. Vroom. In press. Geology and geomorphology of coral reefs of the Northwestern Hawaiian Islands. pp. 519-572. In: B. Riegl and R.E. Dodge (eds.). Coral Reefs of the USA. Coral Reefs of the World, Volume 1. Springer. 806 pp.

Rowan, R. 2004. Thermal adaptations in reef coral symbionts. Nature 430: 742.

Schultz, J.K., R.L. Pyle, E.E. DeMartini, and B.W. Bowen. 2007. Genetic connectivity among color morphs and Pacific archipelagos for the flame angelfish, *Centropyge loriculus*. Mar. Biol. 151(1): 167-175.

Sladek-Nowlis, J., A.M. Friedlander, E.E. DeMartini, and E.K. Brown. In review. Dramatic ecological effects of fishing revealed using a new assemblage assessment tool that relies on a large unfished reference area. Conserv. Biol.

Stat, M. and R. Gates. 2008. Vectored introductions of marine endosymbiotic dinoflagellates into Hawaii. Biol. Invasions 10(4): 579-583.

Stat, M., E. Morris, and R.D. Gates. In review. Functional diversity in coral-dinoflagellate symbiosis. Proceedings of the National Acadamy of Science.

Stewart, B.S., G.A. Antonelis, J.D. Baker, and P.K. Yochem. 2006. Foraging biogeography of Hawaiian monk seals in the Northwestern Hawaiian Islands. Atoll Res. Bull. 543: 131-145.

Stumpf, R.P., K. Holderied, and M. Sinclair. 2003. Determination of water depth with high-resolution satellite imagery over variable bottom types. Limnol. Ocean. 48: 547-556.

Tomczak, M. and J.S. Godfrey. 2003. Regional Oceanography: An Introduction, 2nd edition. Daya Publishing House, Delhi.

U.S. Coast Guard (USCG). 2003. Tern Island ecological risk assessment addendum - Bulky Dump. Technical Memorandum. CH2MHill for US Coast Guard Civil Engineering Unit. Honolulu, HI.

U.S. Fish and Wildlife Service (USFWS). 2005. Regional seabird conservation plan, Pacific Region. Migratory Birds and Habitat Programs, U.S. Fish and Wildlife Service. Portland, OR. 264 pp. http://www.fws.gov/pacific/migratorybirds/reports.htm

Vaughan, T.F. 1907. Recent Madreporaria of the Hawaiian Islands and Laysan. U.S. National Museum Bulletin 59. Smithsonian Institution Press. Washington, DC. 425 pp.

Vroom, P.S. 2005. *Dasya atropurpurea* sp. nov. (Ceramiales, Rhodophyta), a deep water species from the Hawaiian archipelago. Phycologia 44: 572-580.

Vroom, P.S. and K.N. Page. 2006. Relative abundance of macroalgae (RAM) on Northwestern Hawaiian Island reefs. Atoll Res. Bull. 543: 533-548.

Vroom, P.S., K.N. Page, J.C. Kenyon, and R.E. Brainard. 2006. Algae-Dominated Reefs. Am. Sci. 94: 430-437.

Work, T.M., R.A. Rameyer, G. Takata, and M.L. Kent. 2003. Protozoal and epitheliocystis-like infections in the introduced blueline snapper *Lutjanus kasmira* in Hawaii. Dis. Aquat. Org. 37: 59-66.

Western Pacific Regional Fisheries Management Council (WPRFMC). 2004. Bottomfish and seamount groundfish fisheries of the Western Pacific region: 2002 Annual Report. Western Pacific Regional Fisheries Management Council, Honolulu, HI.

Yu, X. and M. McPhaden. 1999. Seasonal Variability in the Equatorial Pacific. J. Phys. Oceanogr. 29: 925-947.

# The State of Coral Reef Ecosystems of American Samoa

Coordinators: Douglas Fenner[1], Meredith Speicher[2] and Sharon Gulick[2]

Contributing Authors: Greta Aeby[3], Susan Cooper Aletto[4,5], Paul Anderson[6], Benjamin Carroll[1], Eva DiDonato[7], Guy DiDonato[8], Virginia Farmer[2], Douglas Fenner[1], Jameson Gove[4,5], Sharon Gulick[2], Peter Houk[9], Emily Lundblad[4,5], Marc Nadon[4,5], Francesca Riolo[1], Marlowe Sabater[1], Robert Schroeder[4,5], Ellen Smith[4,5], Meredith Speicher[2], Christianera Tuitele[2], Alden Tagarino[1], Selaina Vaitautolu[1], Elena Vaoli[10], Bernardo Vargas-Angel[4,5] and Peter Vroom[4,5]

Other Contributors: Paul Brown[11], Edna Buchan[10], Amy Hall[4,5], Jason Helyer[4,5], Scott Heron[12], Jean Kenyon[4,5], Risa Oram[1], Benjamin Richards[4,5], Katerine Schletz Saili[1], Thierry Work[13] and Brian Zgliczynski[4]

## INTRODUCTION AND SETTING

American Samoa consists of five main volcanic islands and two atolls, which are situated in the central tropical South Pacific (Figure 10.1) at approximately 14°S and 170°W. American Samoa is the only U.S. territory located south of the equator. It experiences seasons opposite to those in all other U.S. areas, and has atmospheric and oceanic circulation patterns found in the southern hemisphere. The five volcanic islands are part of a hotspot chain that also includes Upolu and Savaii, the two larger volcanic islands of (independent) Samoa to the west of American Samoa, several seamounts west of Samoa, ridges extending southeast from Tutuila and northwest from Ofu, and an active undersea volcano east of the island of Tau in American Samoa, named Vailuluu. American Samoa also includes two atolls, Swains and Rose, both of which are much older than the volcanic islands and not geologically related.

The American Samoa archipelago is composed of high volcanic islands and low-lying atolls that have narrow reef flats (50-500 m) and steep offshore banks dropping to oceanic depths within 0.5–8 km from shore. The shallow water habitats are composed primarily of fringing reefs, a few offshore banks, and the two atolls. The archipelago (Figure 10.2) lies within the South Equatorial Current, characterized by warm (28-30°C) westward flowing, oligotrophic surface waters, with a deep thermocline (approximately 120-200 m). Area winds are generally light and variable during the austral summer rainy season, except during cyclones, with consistently stronger trade winds from the east-southeast dominating in other seasons (Figure 10.3). All of the islands are seasonally impacted by episodic long period swell generated from the mid-latitude cyclone belts of both the northern and southern hemisphere (30-60° latitude) and more infrequently by large tropical cyclones, which have historically impacted the islands on 2-7 year timescales. These tropical cyclones and related storms may bring large swells, destructive winds and heavy rains.

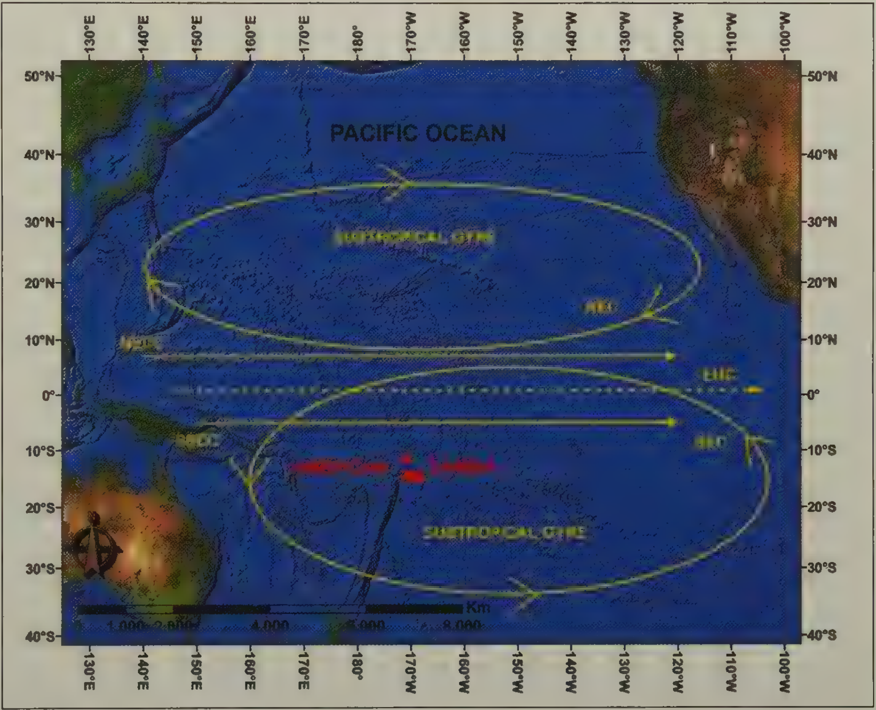


*Figure 10.1. Topographic map showing location of American Samoa and major ocean currents: North Equatorial Current (NEC), South Equatorial Current, North Equatorial Counter Current (NECC), South Equatorial Counter Current (SECC), Equatorial Under Current (EUC). Source: Brainard et al., in review.*

---

1. American Samoa Department of Marine and Wildlife Resources
2. Coral Reef Initiative, American Samoa Coral Reef Advisory Group
3. University of Hawaii, Hawaii Institute of Marine Biology
4. NOAA, Pacific Islands Fisheries Science Center, Coral Reef Ecosystem Division
5. The Joint Institute for Marine and Atmospheric Research
6. American Samoa Environmental Protection Agency
7. National Park Service
8. NOAA National Centers for Coastal Ocean Science, Hollings Marine Lab
9. CNMI, Division of Environmental Quality
10. Mappamondo GIS
11. American Samoa Department of Commerce
12. NOAA Coral Reef Watch
12. U.S. Geological Survey, National Wildlife Health Center, Hawaii Field Office

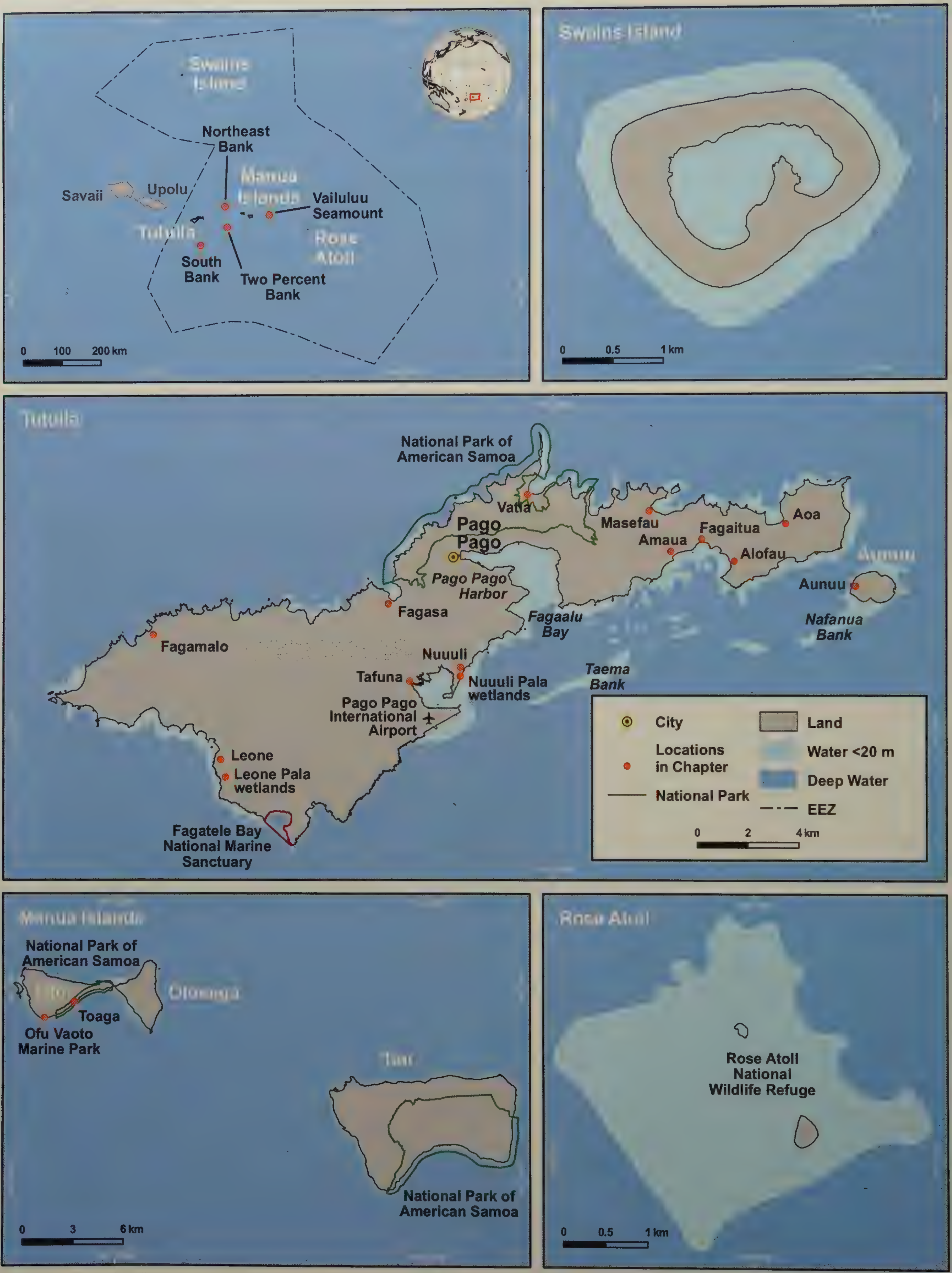

Swains Island
Northeast Bank
Savaii
Upolu
Manua Islands
Vailuluu Seamount
Tutuila
Rose Atoll
South Bank
Two Percent Bank
0 100 200 km
Swains Island
0 0.5 1 km
Tutuila
National Park of American Samoa
Vatia
Pago Pago
Masefau
Fagaitua
Aoa
Amaua
Alofau
Aunuu
Aunuu
Pago Pago Harbor
Fagasa
Fagaalu Bay
Nafanua Bank
Fagamalo
Nuuuli
Tafuna
Nuuuli Pala wetlands
Taema Bank
Pago Pago International Airport
Leone
Leone Pala wetlands
Fagatele Bay National Marine Sanctuary
City
Locations in Chapter
National Park
Land
Water <20 m
Deep Water
EEZ
0 2 4 km
Manua Islands
National Park of American Samoa
Ofu
Olosega
Toaga
Ofu Vaoto Marine Park
Tau
National Park of American Samoa
0 3 6 km
Rose Atoll
Rose Atoll National Wildlife Refuge
0 0.5 1 km

Figure 10.2. A detailed map of American Samoa locations mentioned in this chapter. Map: K. Buja.

Spur and groove reef formations are fairly common on the reef slope. On Tutuila, the reef slope descends to about 20-30 m where it reaches a rubble or sand covered shelf (Figure 10.4). The shelf extends for about 1-4 km and reaches about 100 m depth at its outer edge, ending in a near-vertical escarpment. The escarpment is composed of layers of limestone about 5-10 cm thick and extends down to at least 350 m, where a talus slope of calcareous sand and debris extends below 400 m depth (Wright, 2005).

Multibeam sonar surveys by the NOAA Pacific Islands Fishery Science Center, Coral Reef Ecosystem Division (PIFSC-CRED) team has revealed that the shelf around Tutuila has a number of banks on it, some of which form an interrupted chain resembling a drowned barrier reef, a term used for it as early as 1921 (Chamberlin, 1921; Davis, 1921). Taema Banks at the mouth of Pago Pago harbor and Nafanua Banks, which extends from Aunuu Island toward Taema Banks, are believed to be part of this drowned barrier reef. Although both banks have coral on their outer slope and a portion of their tops, the banks have not yet been explored.

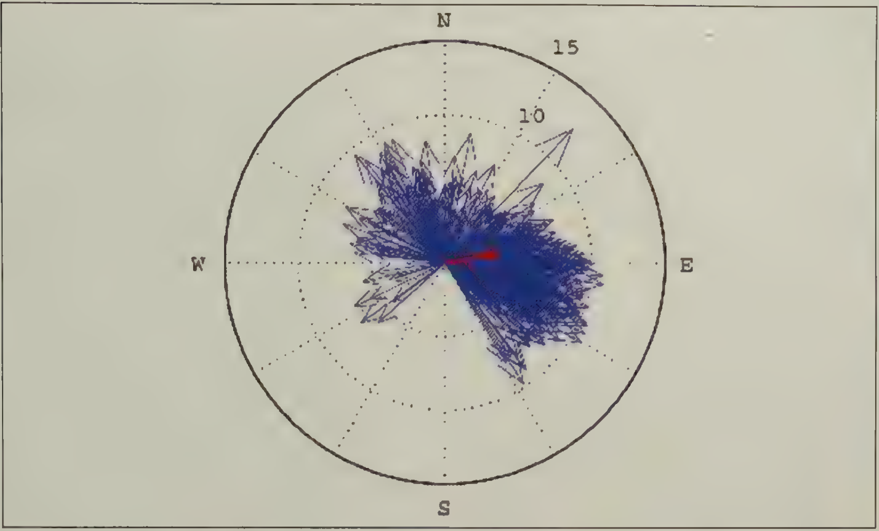


*Figure 10.3. Wind rose derived from CREWS buoy data 2 m above the sea surface at Rose Atoll from 2/8/04 to 4/11/06. Blue arrows are daily averaged wind direction and speed (from 0-15 m/s) and the red arrow is the average for the entire time period, depicting the prevailing light easterly winds. NOTE: Wind vectors point to the direction from which the wind is blowing. Data points outside of three standard deviations from the mean were excluded. Source: PIFSC-CRED, unpub. data.*

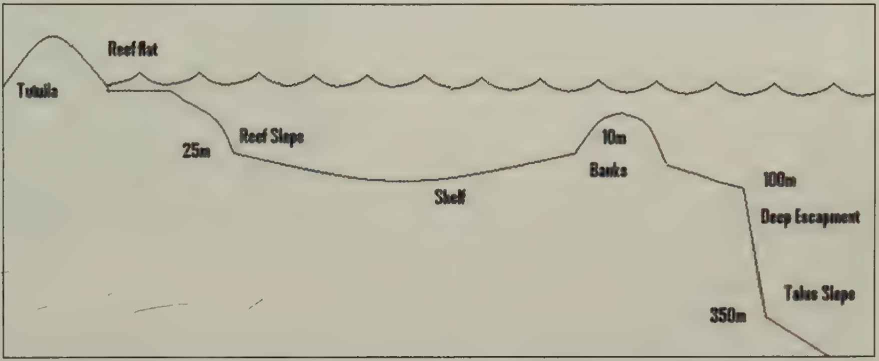


*Figure 10.4. Schematic diagram of the reef and slope features of Tutuila. Not to scale and not proportional. Source: D. Fenner, unpublished.*

The coral reef biota of American Samoa is diverse. Data from initial taxonomic surveys are summarized in Table 10.1 and indicate a total of about 2,705 marine species. Fish are the best studied group, with algae, mollusks and corals following. The total number of marine species recorded to date is slightly less than that known from French Polynesia with 2,876 (Richard, 1985), significantly less than Guam with 5,640 species (Paulay, 2003) and much less than Hawaii with about 7,000 species (Eldredge and Evenhuis, 2003). As additional effort increases the number of species known, total diversity is thought to be much higher than the number of species reported at even the best-studied sites. Biogeography indicates that Hawaii is likely to have fewer species than any of the other sites, so the present numbers probably reflect total effort more than actual diversity. One-hour roving biodiversity searches on slopes in American Samoa result in an average of about 73 species of coral, compared to 93 in the Philippines and 17 in Hawaii recorded by the same observer, supporting the view that local coral diversity is relatively high (D. Fenner, pers. obs.).

The benthic communities of American Samoan coral reefs appear to be in relatively good condition, with crustose calcareous algae dominant, live hard corals second in abundance, dead coral less common (and almost none recently dead), and brown macroalgae very rare on reef flats and slopes. The reefs have experienced a range of major disturbances in recent decades, with a major crown-of-thorns sea star (COTS) outbreak in 1978, hurricanes in 1986, 1990, 1991, 2004 and 2005, mass coral bleaching in 1994, 2002 and 2003, and unusually low tides in 1998, 2005 and 2006. In general, benthic communities have recovered from disturbance, with initial colonization by crustose calcareous algae followed by slower hard coral recovery (Craig et al., 2005). However, an unpublished report by Wass (1982) presented estimates of live coral cover that averaged 63% in the late 1970s. This is approximately double the current live coral cover and suggests that coral populations have not recovered to pre-disturbance levels. Wass also noted that corals in the genus *Acropora* were dominant on reefs, so the present dominance of encrusting corals may indicate a change in benthic community structure. It is possible that Wass (1982) may have estimated coral cover during a peak growth cycle.

Traces of terrestrial sediment have been found on reef slopes, but bays have significant sediment input that stresses corals and has killed coral colonies at times. Water clarity on reef slopes is relatively good with about 25–30 m visibility, but is lower in some bays, the harbor and back reef pools with low flushing rates. Terrestrial runoff from the islands of American Samoa appears to be diluted rapidly beyond the reef crest, but effects of nonpoint pollution on reef slopes has been documented and are thought to be related to pulses of sediment transport during rain events.

Invertebrate filter feeders such as sponges, boring clams, feather duster worms, crinoids, black corals, azooxanthellate soft corals and ascidians are generally rare, small and/or cryptic. There are exceptions in Pago Pago harbor's intertidal zone, where small oysters (*Saccostrea cucculata*) can be found, and in deeper areas of the harbor where sponges and sea fans are common. Also, the inner reef flat at Leone is covered by a thin encrusting grey sponge, and a basalt wall in Amanave has a community of azooxanthellate soft corals. Staghorn corals in back reef pools bleach every austral summer, though corals on reef slopes bleach only during major bleaching events. The fish fauna is dominated by small to medium-sized herbivores (surgeonfish and parrotfish), but rabbitfish are uncommon. Some planktivorous fish, such as small damselfish and fusiliers, are reasonably common on reef slopes, points outside of major bays, and on outer bank reefs. *Chromis* are uncommon on reef slopes and *Anthias* are rare except at Swains. The overall biomass of reef fish on Tutuila is slightly lower than on the Manua Islands, and significantly less than on Swains and Rose. Some species of large reef fish are currently considered uncommon to rare, as is typical of coral reefs near human populations (Friedlander and DeMartini, 2002; Stevenson et al., 2006). Thus, American Samoan reefs appear to be relatively resilient and in fairly good condition.

*Table 10.1. Numbers of species from taxonomic surveys. Sources: [1]Skelton, 2003; [2]Madrigal, 1999; [3]Coles et al 2003; [4]D. Barclay, unpublished; [5]Wass, 1984; [6]L. Whalen and P. Brown, unpublished; and [7]Dolar, 2005.*

| GROUP | NUMBER OF SPECIES |
|---|---|
| Seagrasses | 2[1] |
| Benthic Macroalgae | 237[1] |
| Sponges | 50[2,3] |
| Hard Corals | 276[2,3] |
| other Cnidaria | 59[2,3] |
| Platyhelminthes | 17[2,3] |
| Nemertea | 6[2,3] |
| Nematodes | 1[3] |
| Sipuncula | 1[2,3] |
| Echiurea | 1[2,3] |
| Polychaetes | 79[2,3] |
| Ologochaetes | 1[2,3] |
| Molluscs | 700[2,3,4] |
| Crustacea | 167[2,3] |
| Ectoprocts | 25[2,3] |
| Brachiopods | 1[2,3] |
| Echinoderms | 100[2,3] |
| Ascidians | 22[2,3] |
| Shorefishes | 945[3,5,6] |
| Sea Turtles | 4 |
| Marine Mammals | 11[7] |
| **Total Species** | **2,705** |

## ENVIRONMENTAL AND ANTHROPOGENIC STRESSES

### Climate Change and Coral Bleaching

Six major coral bleaching events have occurred around the world since 1979, with massive coral mortality affecting many reefs (Hoegh-Guldberg, 1999). Increasing sea surface temperatures (SST) associated with climate change are likely to increase the frequency and magnitude of coral bleaching events. American Samoa usually experiences an annual SST range of only 2°C (27.5 to 29.5 °C), although during the past four years, instances of warmer than normal SSTs have been observed (Figure 10.5).

Mass coral bleaching in American Samoa occurred in 1994 (Goreau and Hayes, 1994) and in the summers of 2002 (Fisk and Birkeland, 2002) and 2003 (P. Craig, E. Mielbrecht, pers. comms.). The bleaching in 1994 began in February and was the strongest on record; an average of 32% of coral colonies from a variety of species was still bleached on reef slopes in August during the austral winter (Goreau and Hayes, 1994). Fisk and Birkeland (2002) reported

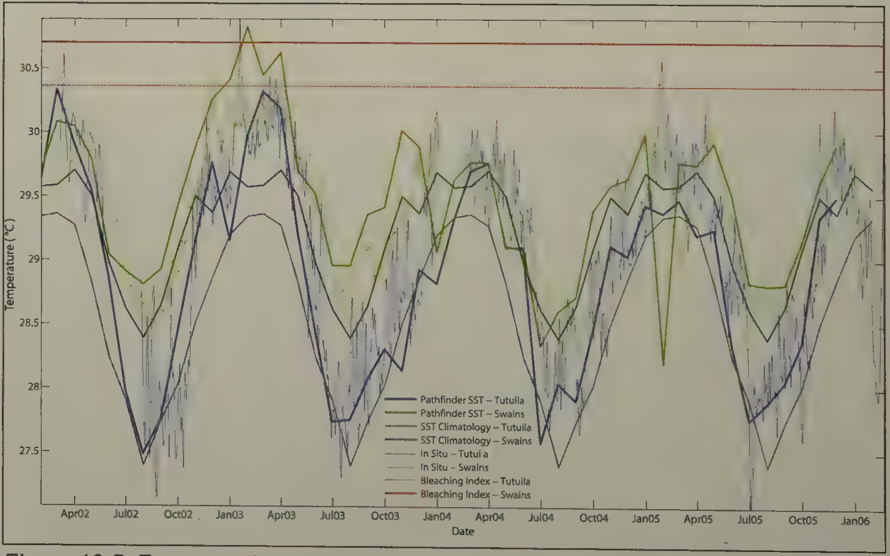


*Figure 10.5. Four year time series of* in situ *sea surface temperature (SST), monthly Pathfinder SST, and Pathfinder SST Climatology from Tutuila and Swains Island.* In situ *SST from both islands exhibits strong intraseasonal variability with temperature fluctuations of 0.5-1.5 °C on daily to weekly timescales. Satellite derived SST primarily shows seasonal temperature changes. Both* in situ *and satellite SST are slightly elevated throughout the time series when compared to the long-term mean (SST Climatology). Coral Reef Watch bleaching threshold of maximum monthly mean SST plus 1°C are included for reference. Source: PIFSC-CRED, unpub. data.*

mild bleaching on reef slopes at a depth of 10 m in March 2002, when 2.3% of colonies on Tutuila and 11.8% of colonies in Manua bleached. On Tutuila, *Montastrea curta* and *Porites lichen* were the most impacted species, while in Manua, *Montipora curta*, *Porites cf. lutea* and *Goniastrea retiformis* had the highest rates of bleaching. In shallow water, *Millepora*, *Acropora* and *Montipora* were the most frequently bleached coral species.

Staghorn corals in American Samoa bleach more intensely on top of branches than on sides or particularly undersides, and in some cases the tops of branches have died while the undersides were only lightly bleached and all but the tops of the branches survived. This is consistent with the view that solar radiation plays a role in the bleaching process along with temperature (e.g., Hoegh-Guldberg, 1999; Fisk and Birkeland, 2002). In a second pattern, only about 5 cm near the branch tip bleaches on all sides.

American Samoa's Territorial Monitoring Program (TMP) has been monitoring bleaching in two back reef lagoon pools on Tutuila from December 2003 to the present. The percentage of bleached colony surface for three species of *Acropora* was estimated based on hour-long timed swims conducted every 2-4 weeks, beginning in December 2003. In addition, temperature loggers were installed in each pool to provide *in situ* measurements of sea water temperatures. The study found a striking correlation between bleaching incidence and seawater temperatures as shown in Figure 10.6. But despite the evidence that acroporid corals have bleached every summer since at least 2002, little colony mortality has occurred. Colony mortality has also been low in natural lagoon pools on Ofu Island, where coral diversity is relatively high (Craig et al., 2001). Research to investigate coral survival in elevated temperature environments is underway (C. Birkland, L. Smith and D. Barshis, pers. comms.). More information about the results of TMP's bleaching surveys appears in the Benthic Habitats section.

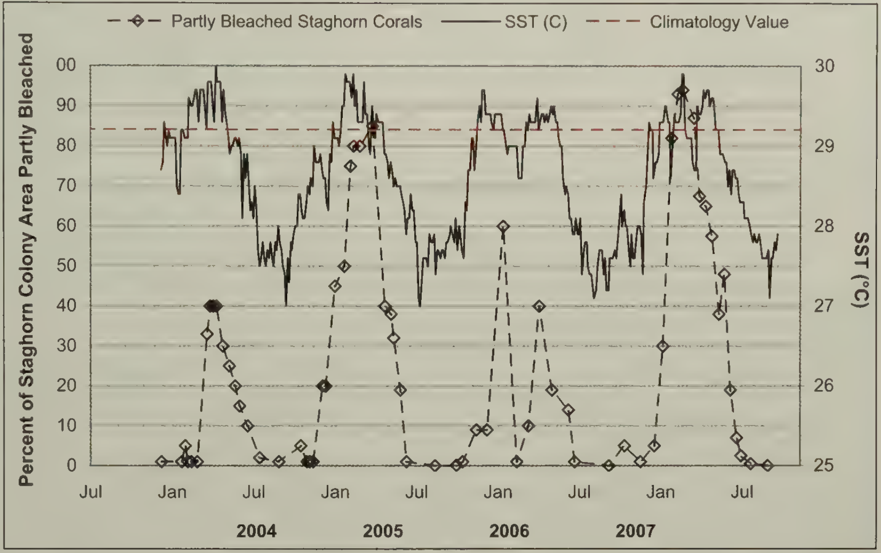


*Figure 10.6. SST time series for the pixel adjacent to the Airport back reef pool, centered at 170.5°W, 15.0°S. The horizontal line shows the climatology value used by NOAA's Coral Reef Watch as an expected summertime maximum temperature threshold for the pixel. Source: Fenner and Heron, unpub. data.*

Bleaching very likely slows or stops growth, and has been reported to block sexual reproduction for a year (Brown and Ogden, 1993; Glynn, 1996; Michalek-Wagner and Willis, 2001). Thus, corals that bleach annually are likely growing less than unbleached corals and are not reproducing other than asexually by fragmentation. It is very likely that bleaching is having a chronic negative impact on these coral populations. The *Acropora*, *Millepora*, and *Porites* colonies described in this section appear to be the first multi-species coral community in the world exhibiting annual summer mass bleaching.

## Diseases

Coral disease is emerging as a problem in the Indo-Pacific, and two studies have documented levels of coral disease present in American Samoa. In one study, diseases were surveyed initially in June 2004 (austral winter) at seven sites around Tutuila to document the baseline levels of disease in the major genera of corals and coralline algae. The same seven sites were resurveyed in January 2005 (austral summer) to look for seasonal differences in disease levels. At each site, two 25 m lines were laid out along depth contours separated by approximately 5 m. Coral colony counts by size class were conducted along each belt transect and colonies were examined for signs of disease. Corals with lesions were photographed, described and a sample taken for histological examination.

From these surveys, 15 coral disease states and two CCA diseases were described from the reefs of American Samoa (Table 10.2). Disease is widespread on the reefs but occurs at low levels (average prevalence=0.14 ± 0.04% SE). The frequency of occurrence (proportion of sites having the disease) varied among the disease states (Figure 10.7) with the two most common coral diseases being *Acropora* white syndrome (AWS) and *Acropora* growth anomalies (AGA; Aeby et al. 2006). These two diseases have a widespread distribution across the Indo-Pacific and have been reported from American Samoa (AWS, AGA; Work and Rameyer, 2005), Australia (AWS, AGA; Willis et al., 2004), Palau (AWS; Willis et al., unpub. data), Marshall Islands (AWS; Pinca et al., 2005), Gulf of Oman (AGA; Coles and Seapy, 1998), Johnston Atoll (AWS, AGA; Work et al., 2001; Aeby and Work, unpub. data ) and the Northwestern Hawaiian Islands or NWHI (AWS, AGA; Work and Rameyer, 2002; Aeby, 2006). Comparative studies in 2004 and 2005 within American Samoa, Johnston Atoll and the NWHI revealed that AGAs were more common in American Samoa. AGAs occurred at 58% of the sites surveyed in 2004 in American Samoa (n=7 sites) as compared to 0% of the sites at Johnston Atoll (n=12 sites) and 33% of the sites within the NWHI (n=11 sites; Work et al., in review). Prevalence of disease (proportion of surveyed corals with disease signs) varied among the seven sites surveyed with the overall disease prevalence ranging from 0.043–0.86% (Aeby et al., 2006).

Disease prevalence also varied among coral genera (Figure 10.8) with *Acropora* having the highest overall prevalence of disease, which is consistent with findings from other areas of the Indo-Pacific. The types and frequency of occurrence of diseases varied between austral winter 2004 and austral summer 2005 (Table 10.3), but the overall disease prevalence was not significantly different.

The two CCA diseases present in American Samoa include coralline lethal orange disease (CLOD; Littler and Littler, 1995) and CCA black fungal disease (Littler and Littler, 1998). CLOD was more common on the reefs (Frequency of Occurrence=57% in 2004 and 42.9% in 2005) than black fungal disease (Frequency of Occurrence=0% in 2004 and 14.3% in 2005). As with coral diseases, no seasonal differences were found in levels of CLOD (Aeby et al. 2006).

The second study of coral disease was conducted throughout the American Samoa archipelago by PIFSC-CRED as part of their standard monitoring cruises in 2002, 2004, and 2006. In 2006, rapid ecological assessments (REA) were conducted at 62 sites to compute the percent of diseased colonies relative to the total number of colonies in each survey area. The study found coral diseases at 38 (61%) of the 62 sites, and that of the 14 genera affected, *Montastrea*, *Favia*, *Montipora*, *Porites*, *Astreopora* and *Acropora* exhibited the greatest frequency of occurrence (93% of cases), and *Favia*, *Coscinaraea* and *Leptoria/Platygyra* showed the greatest prevalence values (Figure 10.9).

Of 22 sites on Tutuila, 55% contained diseased corals, but the overall mean prevalence for the island was 0.13 ± 0.04% SE, values that are comparable to other Pacific islands. PIFSC-CRED surveys indicated that patterns of disease distribution and abundance varied considerably within and among islands in American Samoa. Patterns of disease occurrence and prevalence across the coral taxa also indicated that only a few genera may be disproportionately targeted by disease, suggesting that the ecological impacts of disease may be more severe in populations of uncommon or rare coral taxa. More information about both bleaching studies can be found in the Benthic Habitats section of this chapter.

*Table 10.2. Distribution of coral and CCA disease on the reefs of Tutuila. Data show presence or absence of the disease in each area surveyed in June 2004 and January/February 2005. Coral and CCA cover based on line-intercept method with the average of 2004 and 2005 shown. Source: Aeby et al., 2006.*

| DISEASE | MALOATA | TAFEU | VATIA | LEONE | FAGATELE | FAGAALU | FAGA'ITUA |
|---|---|---|---|---|---|---|---|
| *Acropora* ciliate disease | | | X | | | | |
| *Acropora* white syndrome | | X | X | | X | X | X |
| *Acropora* growth anomalies | X | | X | X | X | | |
| *Porites* focal tissue loss | | | | | X | | |
| *Porites* multifocal tissue loss | | | | X | | | |
| *Porites* growth anomalies | | | | | X | | |
| *Montipora* growth anomalies | X | | | | | | |
| *Montipora* dark spot | | X | | | | | |
| *Pssamacora* dark spot | | X | | X | | | X |
| *Lobophyllia* tissue loss syndrome | | | | | X | | X |
| *Pavona* growth anomalies | | | | | | X | |
| *Pavona* dark spot | X | X | | X | | | |
| *Goniastrea* growth anomaly | | | | X | | | |
| *Leptastrea* growth anomaly | | X | | | | | |
| *Pocillopora* white band disease | | X | | | | | |
| Coralline lethal orange disease | X | | X | X | X | | |
| CCA black fungal disease | | | | | X | | |
| **Avg. coral cover (%)** | **26.6** | **48** | **39.6** | **39.3** | **46** | **29.6** | **26.7** |
| **Avg. CCA cover (%)** | **40.4** | **8.9** | **19.9** | **36.5** | **37.6** | **33.8** | **53.5** |

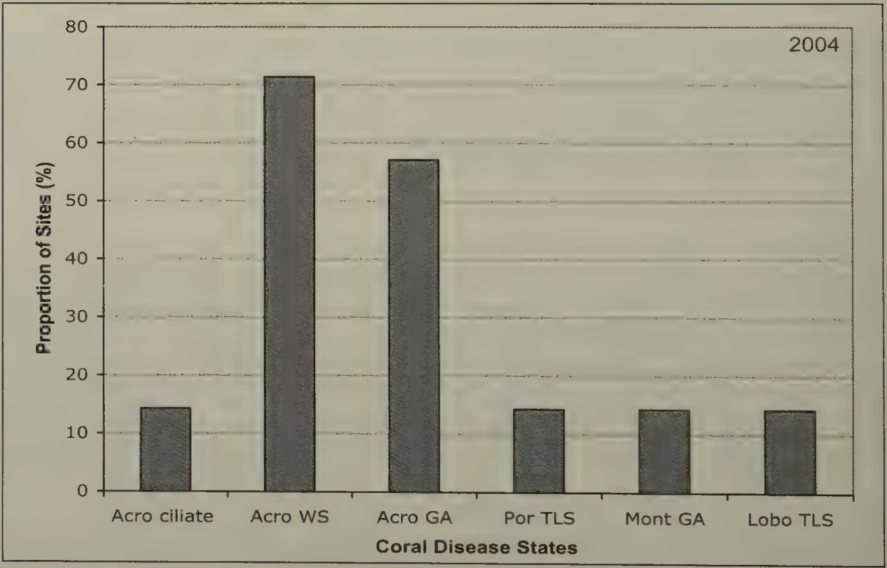


*Figure 10.7. Frequency of occurrence of major coral diseases on Tutuila reefs. Acro=* Acropora, *Por*=Porites, *Mont*=Montipora, *Lobo*=Lobophyllia, *WS=white syndrome, GA=growth anomaly, TLS=tissue loss syndrome. Source: Aeby et al., 2006.*

### *Fish Disease*

Twenty bluelined snapper (*Lutjanus kasmira*) and four goatfish (various species) were examined for presence of infectious organisms. Eighty percent of the bluelined snapper were infected with protozoa in the spleen. This percentage was as high as that observed on Oahu in the Hawaiian Islands (Work et al., 2003). Bluelined snapper also had infections with bacteria in the kidneys but at a low prevalence (<10%). General inflammatory lesions in multiple organs were prominent in bluelined snapper from American Samoa suggesting that fish are responding in a much more prominent way than similar species in Hawaii. For example, liver necrosis was more common in bluelined snapper from American Samoa than those from Oahu. In future studies, it would be of interest to survey fish in different seasons to determine if such an effect exists on prevalence of parasites and pathogens. Also, given that bluelined snapper in American Samoa have such a high prevalence of infection with protozoa in the spleen, it would be of interest to examine fish that school with bluelined snapper to determine whether diseases are shared between species.

## Tropical Storms

American Samoa has been hit by six cyclones in the past 20 years, including three since 2004 (Figure 10.10). In January 2004, Category 5 Cyclone Heta moved through American Samoa causing substantial damage with sustained winds of 120 km/h (75 mph), gusts of 185 km/h (115 mph) and storm surge waves up to 13.5 m (44 ft) high along the northwestern shorelines. Similarly in February 2005, Category 5 Cyclone Olaf moved through American Samoa, also causing substantial damage. Olaf and a 1986 storm were especially damaging to the Manua Islands.

El Niño-Southern Oscillation (ENSO) is an interannual climatic phenomenon (approximately 3–8 years) that creates significant temperature fluctuations in the tropical surface waters of the Pacific Ocean. ENSO events can have a significant impact on coral reef ecosystems due to changing surface winds, ocean currents, water temperatures, nutrient availability, storm frequency and magnitude, etc. The manifestations of ENSO have also been linked to large-scale reef-building coral mortality due to the increased temperatures and UV exposure, as well as decreased nutrients (Hoegh-Guldberg, 1999). ENSO is a naturally occurring phenomenon, however, there is uncertainty regarding how global warming and associated climate changes will impact the frequency and/or magnitude of this cycle and how that will in turn affect coral reef ecosystems. In the American Samoa region, SST values show a negative correlation with ENSO; cooler than normal (0.5-1.0°C) SSTs are observed during positive ENSO phases (El Niño), whereas warmer than normal SSTs are observed during negative ENSO phases (La Niña; Figure 10.11).

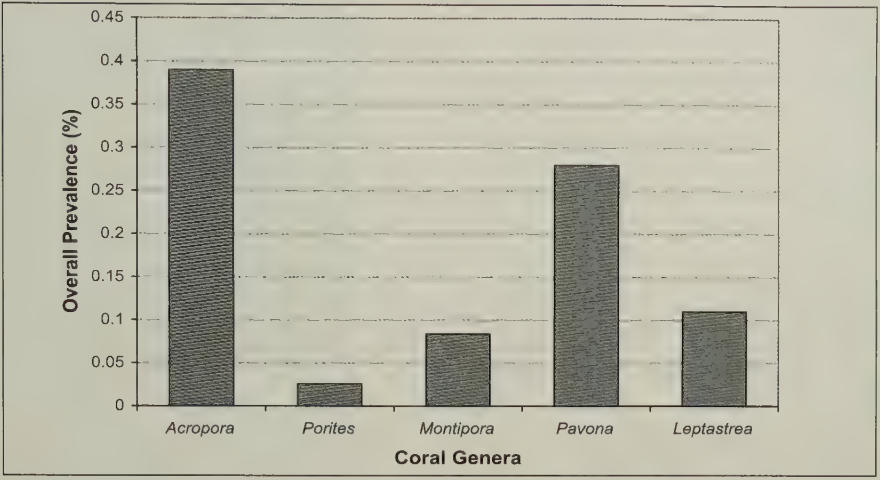


*Figure 10.8. Differences in disease levels among coral genera in American Samoa. Source: Aeby et al., 2006.*

*Table 10.3. Frequency of occurrence of diseases at seven reefs surveyed in June 2004 and January/February 2005. Source: Aeby et al., 2006.*

| | FREQUENCY OF DISEASE OCCURRENCE (%) | |
|---|---|---|
| | SUMMER 2004 | WINTER 2005 |
| *Acropora* ciliate disease | 14.3 | 0 |
| *Acropora* white syndrome | 71.4 | 42.9 |
| *Acropora* growth anomalies | 57.1 | 42.9 |
| *Porites* tissue loss syndrome | 14.3 | 0 |
| *Porites* growth anomalies | 0 | 0 |
| *Porites* multi-focal tissue loss | 0 | 14.3 |
| *Montipora* growth anomalies | 14.3 | 0 |
| *Montipora* dark spot | 0 | 28.6 |
| *Lobophyllia* tissue loss syndrome | 14.3 | 0 |
| *Pavona* growth anomalies | 0 | 14.3 |
| *Pavona* dark spot | 0 | 28.6 |
| *Goniastrea* growth anomaly | 0 | 14.3 |
| *Leptastrea* growth anomaly | 0 | 14.3 |
| Coralline lethal orange disease | 57 | 42.9 |
| CCA Black Fungus | 0 | 14.3 |

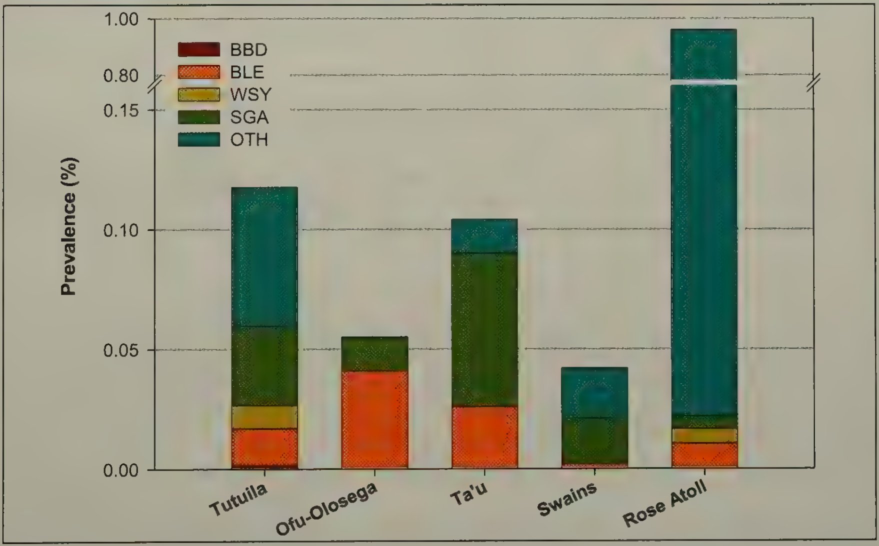


*Figure 10.9. Mean overall prevalence of coral disease in American Samoa relative to coral density (colonies/m$^2$) at each site. BBD: black band disease; BLE: bleaching; WSY: white syndrome; SGA: skeletal growth anomalies; OTH: "other lesions". Source: Brainard et al., in review.*

## Coastal Development and Runoff

Sedimentation is a significant potential threat to the reefs of American Samoa. The islands are very steep and rainfall is often heavy. Currently, steep slopes are almost completely covered by dense native vegetation except in areas cleared for agriculture and quarry operation during prehistoric settlement (Clark and Herdrich, 1993). If a significant amount of vegetation were to be removed, sediment runoff in nearshore areas would likely increase, especially near river mouths, in bays and in other low-flushing areas.

Tutuila, where almost all of American Samoa's estimated population of 66,900 people live (American Samoa Department of Commerce, 2007), has only about 26 km$^2$ (10 mi$^2$) of flat land, almost all coastal. The high and increasing population density and associated construction activities place great strains on shoreline resources. The potential impact of sedimentation on nearshore resources led the Department of Marine and Wildlife Resources (DMWR) Key Reef Species Program to conduct a quantitative assessment of the sedimentation rates along the south shore of Tutuila and determine its effect on sport fish populations. Nine sediment traps were deployed and retrieved monthly at the reef slopes of 12 monitoring sites from January 2006 to February 2007. Six sites were located in embayment areas while six were at topographic points to account for habitat variability. Two additional sites at the mouth of streams (Fagaalu and Fagatogo) were included to determine the amount of sediment delivered by the stream compared to direct terrestrial inputs. The dry weight of sediment was used to estimate sedimentation rates in grams per cm$^2$ per day. Results showed that sedimentation rates in bays averaged 12.1 g/cm$^2$/day, which was significantly higher than at point sites, which averaged 1.4 g/cm$^2$/day (Figure 10.12). Sedimentation rates from stream sites, however, were drastically higher than both bay and point sites at 84.7 g/cm$^2$/day. Such high sediment loads were considered detrimental to coral reefs while rates at the bays and points were considered to have moderate and slight effects, respectively (Pastorok and Bilyard, 1985). There were also some noticeable temporal variations as higher sedimentation rates occurred between January and June, a difference that was more evident at embayment sites than point sites. However, this does not correlate with rainfall or with trends in wave action (expressed in significant wave height in meters) that can resuspend sediments.

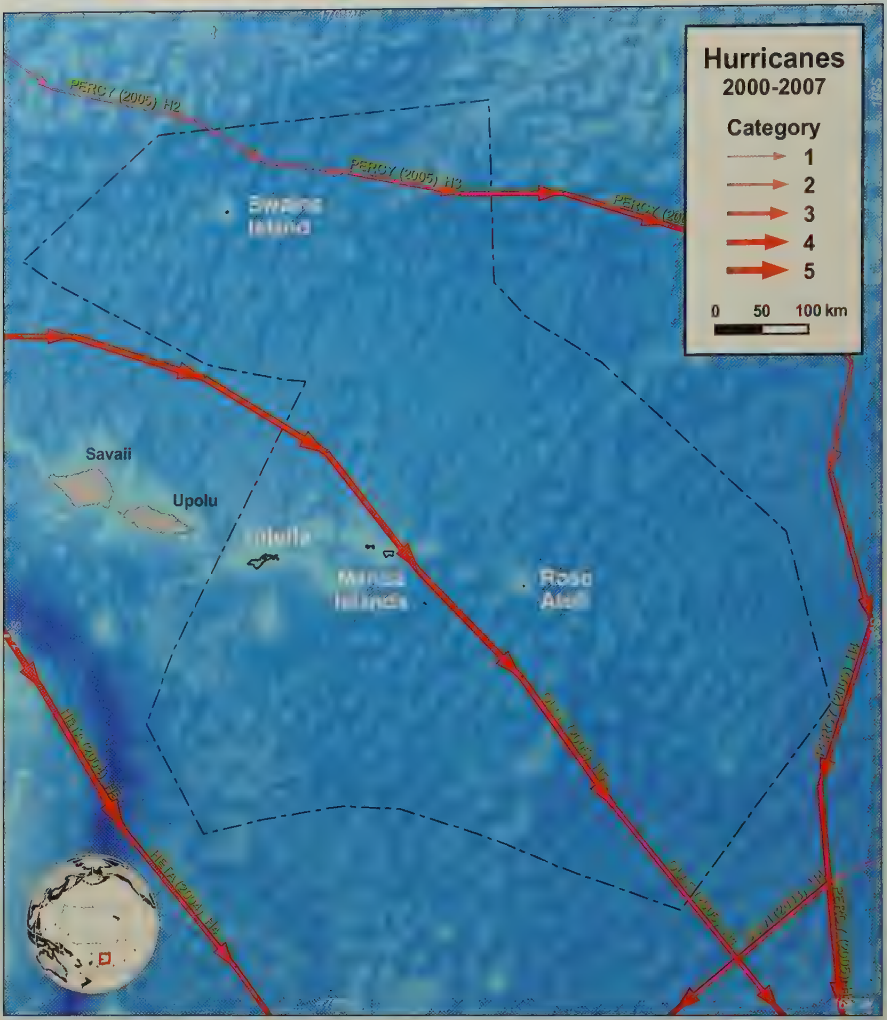


Figure 10.10. A map showing the paths and intensities of tropical storms passing near American Samoa from 2000-2007. Year of storm, name and strength are indicated for each. Map: K. Buja. Source: http://weather.unisys.com/hurricane/.

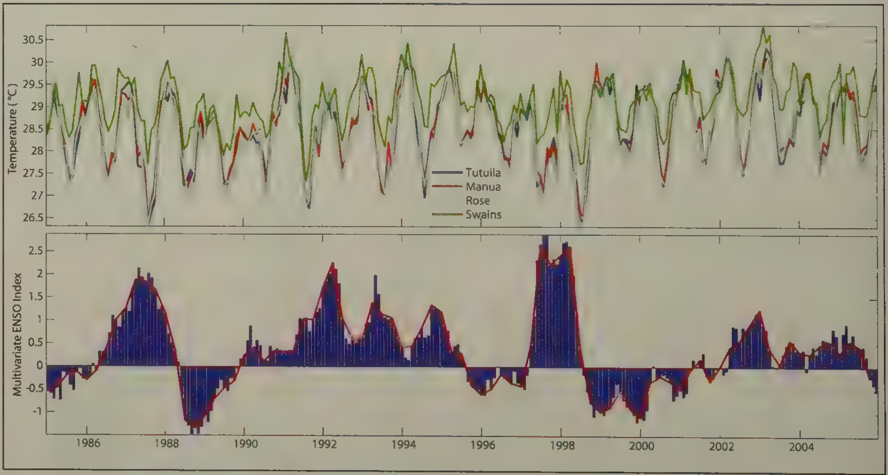


Figure 10.11. Relationship between NOAA Pathfinder derived SST at Tutuila, the Manua group, Rose Atoll and Swains Island (top) and the Multivariate ENSO Index (MEI; bottom) from 1985-2006. Positive MEI values represent El Niño periods while negative values represent La Niña periods. Source: Brainard et al., in review.

High sediment output from stream sites seemed to be dispersed within nearshore areas since only a small amount was detected on reef slopes. Qualitative observation by DMWR biologists suggests that sediments from streams are deposited on reef flats, but no quantitative data has been collected to date. The DMWR Key Reef Species Program will continue to investigate sediment dispersal rates and patterns on reef and possible impacts on juvenile sport fish habitat.

## Coastal Pollution

Currently there are seven National Pollutant Discharge Elimination System permitted discharges in American Samoa. The permitted discharges include treated wastewater from Tutuila's two wastewater treatment plants, effluent from the two tuna canneries, and other point source discharges that could contain minor amounts of oil and other toxic or biological materials. The point sources are not considered major contributors to poor water quality.

Nonpoint source pollution is now considered the primary pollution source for coastal areas in American Samoa. The American Samoa Environmental Protection Agency (ASEPA) developed a *Coastal Nonpoint Source Monitoring Strategy* as part of the American Samoa Coastal Nonpoint Pollution Control Program in order to evaluate the effectiveness of best management practices for achieving water quality objectives through tracking trends in water quality.

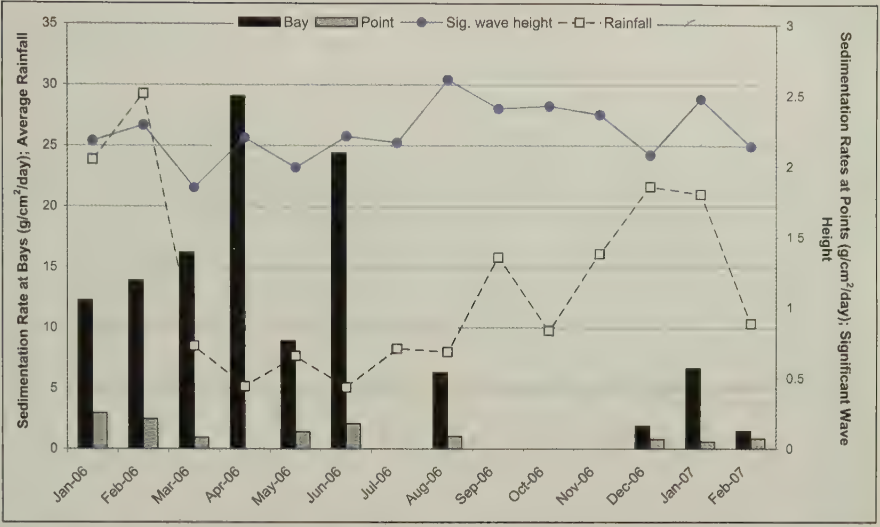


*Figure 10.12. Monthly trend in sedimentation rates (g/cm²/day) on the reef slopes located at embayment (black bar) and topographic point areas (gray bar). Average rainfall (dashed square) and significant wave height (solid circle) were used as driving factors to explain sedimentation trends. Source: Sabater, unpub. data; NOAA-NWS; PIFSC-CRED.*

Pago Pago Harbor is seriously polluted with contaminated sediments and fish processing wastes, which contribute to high bacterial levels that peak during and after heavy rains. Sources of bacterial contamination include piggeries, septic tanks, sewage and animal wastes. ASEPA has issued a general advisory against consumption of fish caught in the inner harbor due to the presence of arsenic, mercury and polychlorinated biphenyls (PCBs). Fish toxicity is attributed to contaminated sediments since the water quality in the harbor meets or exceeds applicable U.S. Environmental Protection Agency (USEPA) water quality standards.

Uncontrolled effluent from piggeries contaminates local watersheds and has resulted in impaired water quality in some coastal waters. Approximately 1,006 piggeries with about 9,000 pigs currently operate in the territory, and the effluent from 82% of them are channeled into deficient cesspools and septic systems or discharge directly into streams or wetlands. Although piggeries are required to have land use permits, 97% are out of compliance (Buchan et al., 2006). ASEPA has been given authority to write citations for piggeries that are out of compliance and has moved forward with a strong enforcement program.

## Tourism and Recreation

There continues to be relatively little tourism in American Samoa. Only two flights a week operate between Honolulu, HI and Pago Pago International Airport for most of the year. There are several flights daily between American Samoa and neighboring independent Samoa and limited service to a few other destinations. It is estimated that American Samoa received 7,762 tourists in 2006 and 7,027 tourists in 2005 (ASDOC, 2007). Approximately 82% of tourists to American Samoa are citizens of the U.S. (52%) or New Zealand (30%).

The Ecotourism Plan for American Samoa, released in June 2005, states that ecotourism is the preferred means of promoting tourism and the economy in the territory (Liu et al., 2005). The objectives of the Ecotourism Plan are: to incorporate ecotourism into the territory's policies and goals for environmental protection; to promote the conservation of American Samoa's natural resources through ecotourism; and to determine the desirable growth rates and limits for the ecotourism industry in the territory.

## Fishing

Reef fish population levels in American Samoa have remained relatively stable throughout the past 30 years while subsistence fishing effort has declined due largely to a shift in the resident population's economic focus away from subsistence activities and toward a cash-based economy. Commercial fishing effort and catch has fluctuated throughout the same time period but is presently also at low levels. More detailed information on reef fish populations and the fishery are provided in the Associated Biological Communities section of this chapter and are analyzed in concert to provide a robust assessment of the status of reef fish populations in American Samoa.

Concerns over the apparent rarity of some larger species of reef fish, including sharks, remain, and a variety of natural and anthropogenic stressors are likely to be contributing factors. In addition to anthropogenic factors such as pollution, habitat destruction and overfishing, low population levels may be a result of naturally occurring distribution patterns, habitat availability, recruitment success, food availability, and other factors. Regardless of the causes, the fact that some species are rare and thus vulnerable to local extinction was considered sufficient reason to protect the remaining individuals. The DMWR recently made the decision to fully protect (i.e., year-round, no-take of individuals of all sizes) all species of sharks, as well as four species of reef fish (humphead or Maori wrasse, *Cheilinus undulatus*; bumphead parrotfish, *Bulbometopon muricatum*; giant grouper, *Epinephelus lanceolatus*; and giant trevally, *Caranx ignobilis*). The decision to protect these species was aided by the fact that they are not heavily targeted by fishers or currently of particular cultural importance. Other considerations included the ecological importance of some of these species, their threatened status in many parts of the world, and their inclusion on lists such as the Convention on International Trade in Endangered Species, the International Union for the Conservation of Nature's (IUCN) Red List, and the U.S. National Oceanic and Atmospheric Administration's (NOAA) Species of Concern. It is hoped that actions to protect these species will maintain or increase population levels; any such changes will be documented by long-term monitoring programs.

## Trade in Coral and Live Reef Species

There is no trade in coral and live reef species at this time.

## Ships, Boats and Groundings

As reported in Craig et al. (2005), nine foreign-flagged longliners were grounded on reefs in Pago Pago Harbor during Hurricane Val in 1991. They were removed in 2000 by building a causeway for machinery to reach each longliner for removal. During preparations in 1999, approximately 1,000 corals were removed from areas planned for the causeways. Although a storm damaged most of the removed corals, over 300 colonies were transplanted into the footprint of one of the vessels at Onesosopo near the mouth of the harbor. The survival, growth, and live tissue status of 354 transplanted corals were evaluated in 2001 when 91–92% had survived and 2005 when 60–78% had survived. Massive *Porites* species and *Pocillopora eydouxi* had significantly higher survival rates than small and mid-sized *Pocillopora* species. Transplanted corals fared as well as controls in terms of survival, growth and change in live tissue cover (Kolinski, 2006). One of the nine longliners was removed whole and scuttled outside the harbor. It was sighted in early 2007 resting intact on a sand patch near the outer reef at Taema Banks in water depths of about 30 m. Some corals had begun to grow on it.

## Marine Debris

A limited amount of marine debris washes in from offshore and is deposited on American Samoa's coral reefs. The bulk of marine debris in the territory originates from land-based activities. Local resource management agencies and community groups organize occasional beach cleanups. NOAA's Office of Response and Restoration is providing technical assistance in planning for the removal of two additional derelict vessels and vessel debris. The vessels in question are deteriorating and scattering debris in nearshore areas, which harms corals and limits human uses of the areas due to concerns about the presence of sharp metal in the intertidal and nearshore subtidal zones. The development of removal plans is expected to assist the territory in seeking funding opportunities for vessel removal.

## Aquatic Invasive Species

A study of introduced marine species in American Samoa did not reveal any that were considered invasive or threatening (Coles et al., 2003).

## Security Training Activities

Security training activities are not considered a major threat to coral reef ecosystems in American Samoa.

## Offshore Oil and Gas Exploration

No oil and gas exploration occurs in American Samoa.

## CORAL REEF ECOSYSTEMS—DATA-GATHERING ACTIVITIES AND RESOURCE CONDITION

A number of monitoring programs have collected data on the status of coral reef ecosystems in American Samoa as described in Table 10.4 and depicted in Figure 10.13.

*Table 10.4. Ongoing monitoring activities in American Samoa. Source: D. Fenner.*

| PROJECT | LOCATION | YEAR | AFFILIATION/ FUNDING | PRINCIPLE INVESTIGATOR | FREQUENCY | STATUS |
|---|---|---|---|---|---|---|
| Aua Transect | Aua Village, Tutuila | 1917 | CRAG, CRI | Birkeland | Periodic | Ongoing |
| TMP | Tutuila and Manua | 2005 | DMWR, CRAG, NOAA | Fenner and Carroll | Annual | Ongoing |
| Resource Assessment and Monitoring Program | All Islands | 2002 | NOAA PIFSC-CRED | Brainard et al. | Biannual | Ongoing |
| Key Reef Species (fish) | Tutuila and Manua | 2005 | DMWR, FedAid Sportfish Recovery | Sabater | Annual | Ongoing |
| Coral Disease | Tutuila and Manua | 2005 | DMWR, FedAid Sportfish Recovery | Fenner | Annual | Ongoing |
| Rose Atoll | Rose Atoll | 2002 | USFWS | Maragos | Periodic | Ongoing |
| MPA Reef Flats | MPA Villages, Tutuila | 2004 | DMWR, FedAid Sportfish Recovery | Vaitautolu | Approx. Annual | Ongoing |
| Fagatele Bay Monitoring | Fagatele Bay, Tutuila | 1985 | Fagatele Bay NMS | Birlkeland and Green | 3 years (Approx.) | Ongoing |
| Long-Term Monitoring | Tutuila and Manua | 1982 | DMWR | Green and Birkeland | 5 years (Approx.) | Ongoing |
| Nonpoint Source Pollution | Tutuila | 2003 | AS EPA | Houk and Peshut | Annual | Ongoing |
| Inshore Creel Survey | South Shore, Tutuila | 1978 | DMWR, FedAid Sportfish Recovery | Iramatra | Daily | Ongoing |
| Reef Monitoring | National Park, North Shore, Tutuila | 2007 | National Park of American Samoa | Brown and Craig | Annual | Ongoing |
| Stream/ Beach Monitoring | Tutuila | 2002 | AS EPA | Zennaro and Paselio | Weekly | Ongoing |
| Shallow-water Benthic Habitat Maps | All Islands | 2005 | NOAA CCMA-BB | Battista and Monaco | One Time | One Time |

### *Economic Valuation of Coral Reefs and Adjacent Habitats in American Samoa*

In October 2006, the American Samoa Coral Reef Advisory Group (CRAG) released an economic valuation of American Samoa's coral reef resources, prepared by Jacobs, Inc. in association with MRAG Americas, the National Institution of Water and Atmospheric Research, and Professor N. Polunin.

As of 2004, the coral reefs of American Samoa provide benefits on the order of $5.1 million/year, and the territory's mangroves add an additional $0.75 million/year. Together, these critical natural resources account for 1.2% of the American Samoa GDP. A few of the most important benefits provided by coral reefs include: $689,000/year benefit due to coral reef fisheries; $73,000/year benefit resulting from recreational uses; $70,000/year benefit deriving from bottom fishing; $447,000/year benefit relating to shoreline protection provided by the reefs. These are just some of the benefits, economic and otherwise, American Samoa stands to lose without continued efforts to increase our understanding of and protect these fragile ecosystems. In addition to the above, a gain of $2,753,000/year in direct benefits could be realized through the complete and effective implementation of proposed mitigation and enhancement measures, as well as management initiatives such as strengthening fisheries regulations and controlling coastal development.

## WATER QUALITY AND OCEANOGRAPHIC CONDITIONS

The health, function and biogeography of American Samoa's coral reef ecosystems are influenced by regional oceanographic conditions. The broad and diverse biological community comprising these ecosystems including fish, corals and other invertebrates, algae, turtles and marine mammals is heavily influenced by ocean currents, waves, temperature, salinity, turbidity, nutrients and other measures of water quality and oceanographic conditions. As these conditions change, so do the physical condition, distribution, abundance and species diversity of reef communities. Table 10.5 presents long-term oceanographic monitoring methods and equipment used in American Samoa since 2002.

The previous edition of this report (Craig et. al., 2005) summarized surface water quality monitoring activities conducted by ASEPA before 2003. Prior to 2003, few data were available for assessing nearshore regions of the territory. As a result, ASEPA, in collaboration with local environmental resource agencies and federal partners such as the National Park of American Samoa (NPAS), began concentrated monitoring and assessment efforts to document coastal water and coral reef condition in order to protect and enhance aquatic life and human health.

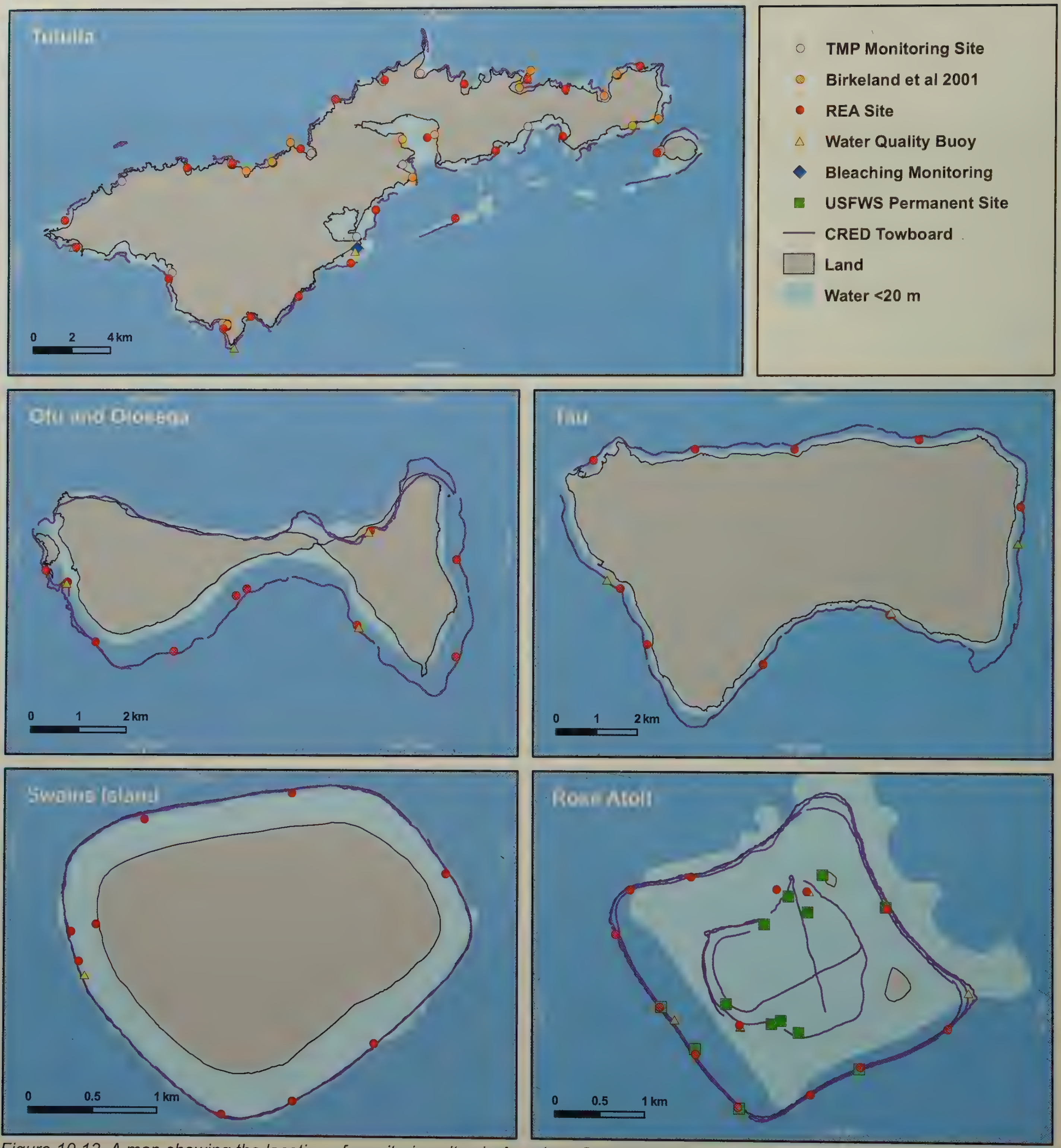

Tutuila
0 2 4 km
○ TMP Monitoring Site
● Birkeland et al 2001
● REA Site
△ Water Quality Buoy
◆ Bleaching Monitoring
■ USFWS Permanent Site
— CRED Towboard
▨ Land
▨ Water <20 m
Ofu and Olosega
0 1 2 km
Tau
0 1 2 km
Swains Island
0 0.5 1 km
Rose Atoll
0 0.5 1 km

*Figure 10.13. A map showing the location of monitoring sites in American Samoa. Map: K. Buja.*

## *NPS/ ASEPA Ocean Monitoring and Assessment*

In 2004, NPS and ASEPA collaborated to conduct a probabilistic-based, comprehensive ocean assessment that evaluated and assessed the quality of the territory's coastal waters. Following the EPA's Environmental Monitoring and Assessment Program, 50 coastal sampling locations in areas up to 0.4 km (0.25 mi) from the mean high water mark were randomly selected from around Tutuila and the Manua Islands. Monitoring targets included several water quality indicators, sediment quality, biota and habitat. For logistical reasons, not all parameters were measured at all stations.

### *Results and Discussion*

Water quality around Tutuila and the Manua Islands was found to be fair to good, depending on the criteria used. The results of the overall assessment using American Samoa Water Quality Standards (ASWQS) are presented in Figure

*Table 10.5. Ongoing oceanographic monitoring activities in American Samoa. Source: PIFSC-CRED.*

| System | Variables Monitored | Dates | Agency |
|---|---|---|---|
| Deepwater CTDs* at select locations near the islands | Conductivity (salinity), temperature, depth, dissolved oxygen, chlorophyll to a depth of 500 m | February 2002 - present | PIFSC-CRED |
| Shallow-water CTDs* - multiple sites each island/atoll | Temperature, salinity, turbidity | February 2002 - present | PIFSC-CRED |
| Water Samples | chlorophyll and nutrients (nitrate, nitrite, silicate, phosphate) concurrent with deep and shallow-water CTDs at select depths | January 2006 - present | PIFSC-CRED |
| Coral Reef Early Warning Buoys -1 Standard (Rose Atoll) | Enhanced: temperature (1 m), conductivity (salinity), wind, atmospheric pressure | February 2002 - present | PIFSC-CRED |
| Sea Surface Temperature (SST) Buoys - 3 (Tau, Tutuila) | Temperature at 0.5 m | February 2002 - present | PIFSC-CRED |
| Subsurface Temperature Recorders - 33 (all islands) | Temperature at depths between 0.5 m and 30 m | February 2004 - present | PIFSC-CRED |
| Ocean Data Platforms (ODP) - 1 (Swains) | Temperature, conductivity (salinity), spectral waves, current profiles | February 2002 - present | PIFSC-CRED |
| Wave and Tide Recorders (WTR) - 2 (Rose Atoll, Tutuila) | Wave and tidal heights | February 2004 - present | PIFSC-CRED |
| Ecological Acoustic Recorder (EAR) - 4 (Tutuila) | Ambient sounds up to 12.5 kHz and vessel generated sounds | February 2006 - present | PIFSC-CRED |

* CTD: Conductivity, temperature and depth.

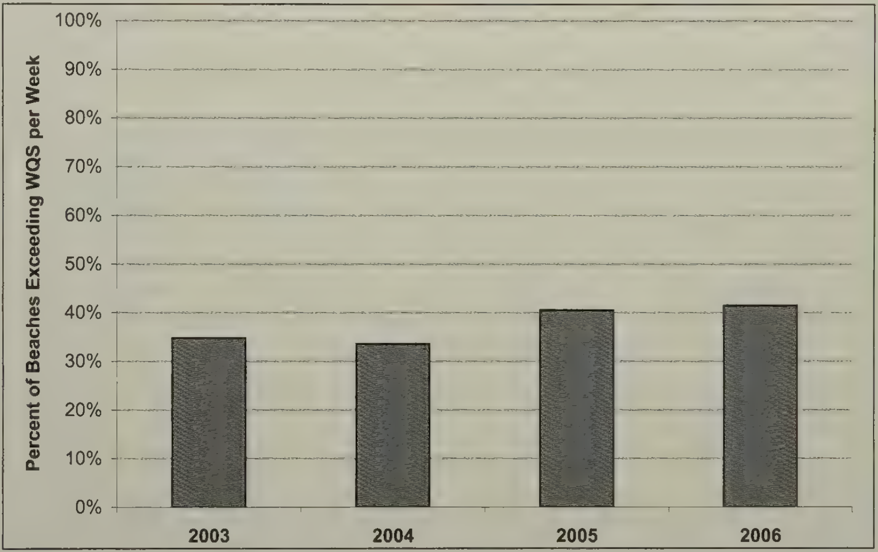


*Figure 10.14. Percentage of beaches exceeding the American Samoa WQS for* Enterococcus *as detected in ASEPA weekly beach monitoring. Source: ASEPA.*

10.14. One hundred percent (100%) of territorial waters complied with the pH standard. Although there are no territorial standards for dissolved inorganic nitrogen (DIN) or dissolved inorganic phosphate (DIP), Lapointe (1997) proposed nutrient thresholds (DIN: 1.0 µM; DIP: 0.1 µM) for oligotrophic marine waters that, when exceeded, might indicate or portend nutrient-related reef degradation. The assessment data showed that 11/49 stations (22%) exceed Lapointe's threshold for DIN. However, all 49 stations exceeded the threshold for DIP, suggesting that sources of phosphate in American Samoa are natural (e.g., weathering of volcanic rock, seabird inputs). There is a significant concern that increased inputs of nitrogen from anthropogenic activities will influence productivity and increase the likelihood of a shift in benthic composition of nearshore reefs from hard corals to macroalgae. The data also imply that high chlorophyll is not generally the cause of reduced water clarity. The overall total suspended solids (TSS) value for waters that failed the clarity standard was significantly higher than at stations that passed the clarity standard, implying that TSS may be a significant factor in water clarity at the station level and may be a significant problem territory-wide.

In terms of sediment contamination, the available data suggest a generally low level of impact in the territory. There were no detectable levels for polycyclic aromatic hydrocarbons (PAHs), PCBs or pesticides, but three metals were present in sediments at levels that exceeded established thresholds of interest: arsenic, chromium and nickel. The presence of these metals at all sampled sites suggests that natural sources may contribute to metal concentrations around the territory, however, the high levels of arsenic, chromium and nickel found at specific sites suggest that anthropogenic sources may be significant. It is important to note that sediments collected under this study only represent about 32% of the territory and that only one station was located within the boundaries of Pago Pago Harbor, which is known to have significant sediment contamination from previous military and industrial usage.

The levels of contamination in fish tissues collected during the study were often low, and only rarely reached levels of concern for human consumption. In only two cases did concentrations exceed levels considered safe for consumption by the U.S. EPA (2000) for mercury and total PAHs. These findings suggest that approximately 4% of American Samoa's nearshore habitats contain fish with contaminants at levels that may be unsafe to eat. In addition, the findings indicate that bioaccumulation of toxins is minimal, but still occurring.

## Lagoon Monitoring

Periodically, algal blooms occur in front of Olosega Village in Manua. In May 2006, in order to determine the sources of nutrients to the lagoons of Ofu and Olosega islands, a research team led by Virginia Garrison, U.S. Geological Survey, examined the nutrient content of the two most common species of seaweed (*Halimeda* sp. and *Dictyosphaeria versluysii*) that occur on the reef flats in front of each village and compared the findings from those sites with a relatively pristine lagoon/reef flat. Benthic cover at each of the three sites was determined using the point-intercept method. Algal species were analyzed for nitrogen isotopes 14N and 15N and δ13C.

*Results and Discussion*

Results from this pilot study indicate that the major sources of nutrients to the three lagoons are most likely oceanic, atmospheric and/or sedimentary, and not derived from animal or terrestrial sources. High volumes of oceanic waters and strong currents flush the lagoons daily and would be expected to rapidly dilute any nutrient input from land. These findings provide baseline data to compare to future data from algal blooms (Garrison et al., 2007).

## ASEPA Beach Monitoring

Utilizing a health-based, tiered monitoring approach, the ASEPA began monitoring 48 recreational beach locations in American Samoa spanning approximately 149 shoreline miles. Forty-two (42) beach sites are sampled at a weekly frequency, and six at a monthly frequency. Samples are analyzed for *Enterococci* using Enterolert® and most probable number methods and compared to the ASWQS to determine compliance.

*Results and Discussion*

Monitoring results from 2003 that were presented in the previous report (Craig et al., 2005) indicated that the territory's bathing beaches often exceeded the ASWQS for *Enterococcus*. Since that time, beach monitoring efforts have continued and expanded, but little change was detected in concentrations of *Enterococcus* in nearshore waters used primarily for swimming. Improper treatment and disposal of human and animal waste remain likely sources of contamination. Recent ASEPA program developments addressing animal waste management shows some promise in reducing bacterial levels in nearshore coastal waters. Beach monitoring will continue to determine trends and evaluate the effectiveness of environmental compliance and enforcement actions.

## ASEPA Biological Criteria Monitoring

The dynamic nature of water quality data makes it very difficult to properly assess a region, project or pollutant source without appropriate sample sizes. At any particular time, water quality measurements are affected by rainfall, storm events, tidal fluctuations, and other atmospheric and oceanographic conditions. One cost- and time-efficient approach is to examine biological communities that are bathed by the waters in question since in tropical marine waters these communities will shift in response to nutrients, sediment loads, turbidity and other parameters (Littler and Littler, 1985; Rogers, 1990; Telesnicki and Goldberg, 1995; Valiela, 1995; Lapointe, 1997; Fabricius and De'ath, 2001). This forms the basis upon which American Samoa's biological criteria (coral reef) monitoring program was initiated.

The goal of the ASEPA coral reef monitoring program is to carry out a long-term investigation using a stratified approach based on geological setting to detect changes over time resulting from land-based human disturbance. This effort started in 2003 when six watershed-based survey sites were established around Tutuila (Houk et al., 2005), and was expanded in 2005 and 2007 when ten additional sites were added (Houk, 2005; Houk and Musburger, 2007). Initial surveys were conducted to characterize coral reef development at the monitoring stations to account for the inherent variation that results from a reef's geological and oceanographic setting (Houk et al., 2005; Goreau, 1959; Van Woesik and Done, 1997; Grigg, 1998; Pandolfi et al., 1999). Subsequently, the relationships between watershed volume, human population density, and coral reef communities were examined within each distinct "setting" to determine which ecological measures were most responsive to proxies of pollution.

Targeted monitoring sites were established on reefs adjacent to stream discharges, at a distance of about 250 m from each mouth. Data on benthic cover, coral community composition, and macroinvertebrate and fish abundance was collected at 9–11 m depth. A detailed description of study methods can be found in Houk and Musburger (2007).

*Results and Discussion*

Three, statistically distinct geomorphological settings (referred to as classes herein) exist among the 16 survey locations included in this study (Figure 10.15). Class 1 reefs have an unconsolidated, limestone framework representing localities where the greatest Holocene deposition has occurred, and include the numerous bays situated on the south side of Tutuila. Class 2 reefs consist of a consolidated, limestone framework that allows for the modern growth of relatively large massive and encrusting corals, and is represented by the majority of sites on the north side of Tutuila. A third class (class 3) is represented by one site on the north at Vatia and is unique based upon a lack of limestone deposition and a dominance of sand, perhaps a consequence of geological infilling.

Negative correlations were consistently found between three watershed descriptors (size, percent disturbed land and human population) and three biological measures (coral species richness, community evenness and the percentage of benthic substrate favorable for coral growth) across class 1 and 2 reefs. Similar, significant, negative correlations between proxies to watershed pollution and biological measures in both classes portray causation by the environment upon the adjacent reefs. Both human population and disturbed land are dependent upon watershed area to some degree, however correlations were not significant. Thus, patterns are best described by proxies to watershed pollution rather than size alone.

Six of the 16 sites were classified as "not supportive" for ASEPA's aquatic life use criteria: Fagaalu, Laulii, Matuu, Alofau, Fagasa, and Fagafue (USEPA, 1997, 2002; Table 10.6). Six sites were classified as "partially supportive": Fagaitua, Leone, Vaitogi, Aoa, Masausi, and Masefau. Two sites were classified as "fully supportive": Fagatele and Tafeu.

Trend data from five sites show that the 2005 bleaching event had an effect on the benthic community with a shift from structurally-complex coral cover to mixed coralline and turf algae cover. Ideally, such a disturbance should have minimal impact upon a reef "health" index assuming the community remains resilient and a phase shift is not imminent. In three cases, at Masefau, Fagaitua and Leone, despite a decrease in coral cover, the overall aquatic life use support rank remained relatively consistent. In two contrasting instances, at Aoa and Alofau, the loss of coral cover was accompanied by a large increase in turf and coralline algae cover and little new coral growth, resulting in drastically lower rankings and suggesting slow or halted recovery. Notably, the Leone and Masefau sites displayed relatively minimal impacts to the cover and structure of coral assemblages as a result of the bleaching event.

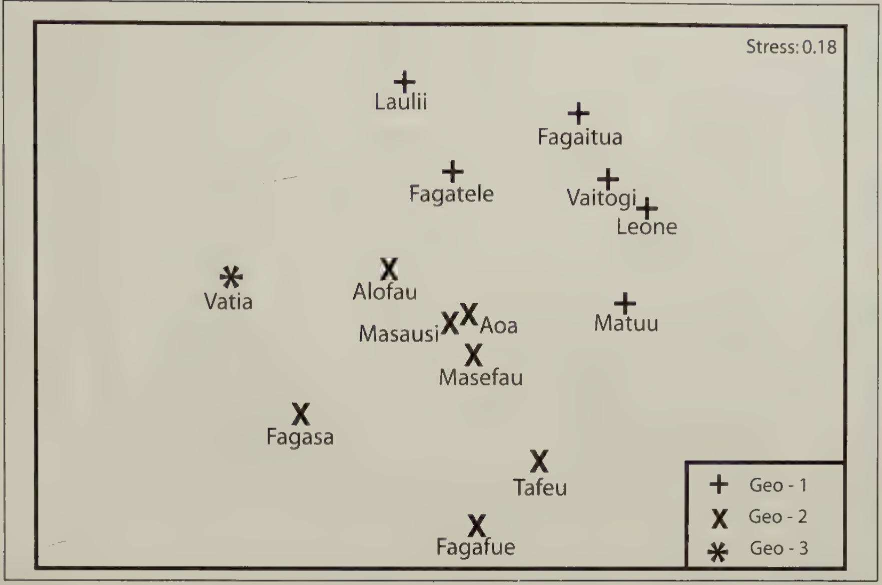


*Figure 10.15. Multi-dimensional scaling diagram showing significant differences in coral community structure based upon site geomorphology (Global R-statistic= 0.77, Pairwise R-statistic >0.6 for all). Source: Houk and Musburger, 2007.*

*Table 10.6. ASEPA aquatic life use support (ALUS) rankings. The overall biocriteria, or reef health score, is the average of all biological measures which ranges between 0 (lowest)–1 (pristine). Final ALUS rankings are based from this average as follows; 0.8–1.0="fully supportive", 0.6–0.8="partially supportive", and 0.0–0.6="not supportive" for aquatic life (EPA, 1997, 2002). Source: Houk and Musburger, 2007.*

| SITE | YEAR | GEO CLASS | COMMUNITY RANK | BENTHIC COMMUNITY RANK | OVERALL AVERAGE | ALUS RANKING |
|---|---|---|---|---|---|---|
| Fagaalu | 2003 | 1 | 0.59 | 0.19 | 0.39 | Not |
| | 2005 | 1 | 0.54 | 0.22 | 0.38 | Not |
| | 2003 | 1 | 0.78 | 0.81 | 0.80 | Fully |
| Fagaitua | 2007 | 1 | 0.97 | 0.57 | 0.77 | Partially |
| Fagatele | 2005 | 1 | 0.84 | 0.75 | 0.80 | Fully |
| Laulii | 2005 | 1 | 0.65 | 0.51 | 0.58 | Not |
| | 2003 | 1 | 0.70 | 0.70 | 0.70 | Partially |
| Leone | 2005 | 1 | 0.81 | 0.55 | 0.68 | Partially |
| | 2007 | 1 | 0.61 | 0.76 | 0.69 | Partially |
| Matuu | 2007 | 1 | 0.74 | 0.44 | 0.59 | Not |
| Vaitogi | 2007 | 1 | 0.47 | 1.00 | 0.74 | Partially |
| | 2003 | 2 | 0.66 | 0.73 | 0.69 | Partially |
| Alofau | 2007 | 2 | 0.81 | 0.20 | 0.51 | Not |
| | 2003 | 2 | 0.84 | 1.00 | 0.92 | Fully |
| Aoa | 2007 | 2 | 0.84 | 0.43 | 0.64 | Partially |
| Fagafue | 2007 | 2 | 0.60 | 0.17 | 0.39 | Not |
| Fagasa | 2005 | 2 | 0.67 | 0.21 | 0.44 | Not |
| Masausi | 2005 | 2 | 0.82 | 0.47 | 0.65 | Partially |
| | 2003 | 2 | 0.92 | 0.21 | 0.57 | Partially |
| Masefau | 2007 | 2 | 0.93 | 0.29 | 0.61 | Partially |
| Tafeu | 2005 | 2 | 0.96 | 0.66 | 0.81 | Fully |

## BENTHIC HABITATS

### *DMWR's Territorial Monitoring Program*

This program monitors eleven sites annually: ten on the reef slope around Tutuila and one on Aunuu. Data collection began in 2005. At each non-reef flat site, four 50-m tapes are laid along the 8-10 m depth contour. Benthic cover is recorded in functional categories under a point at each half meter, with coral life form and species recorded where possible (Whaylen and Fenner, 2006; Fenner and Carroll, unpub. data). Two transect tapes were laid per site on reef flats at the 11 sites starting in 2007. Coral rapid assessment dives are carried out at each of the 11 sites with a 60-minute roving dive ascending from the base of the reef slope (usually about 20 m depth) to the limits of safety near the reef crest. Estimates of the abundance of all coral species encountered are recorded in the DAFOR scale (dominant, abundant, frequent, occasional, rare).

*Results and Discussion*

TMP found in both 2005 and 2006 that the most abundant benthic cover on Tutuila reef slopes at 9 m depth was CCA, followed by live corals, turf algae and branching coralline algae (Figure 10.16). Other benthic cover types were minor contributors, except at a few specific locations. All macroalgae were either the green calcarious alga *Halimeda*, or branching coralline algae. No brown macroalgae were recorded. There were no recently dead corals in transects in either 2005 or 2006, and the percentage of dead corals covered with algae was low, with only 2.6% cover in 2006.

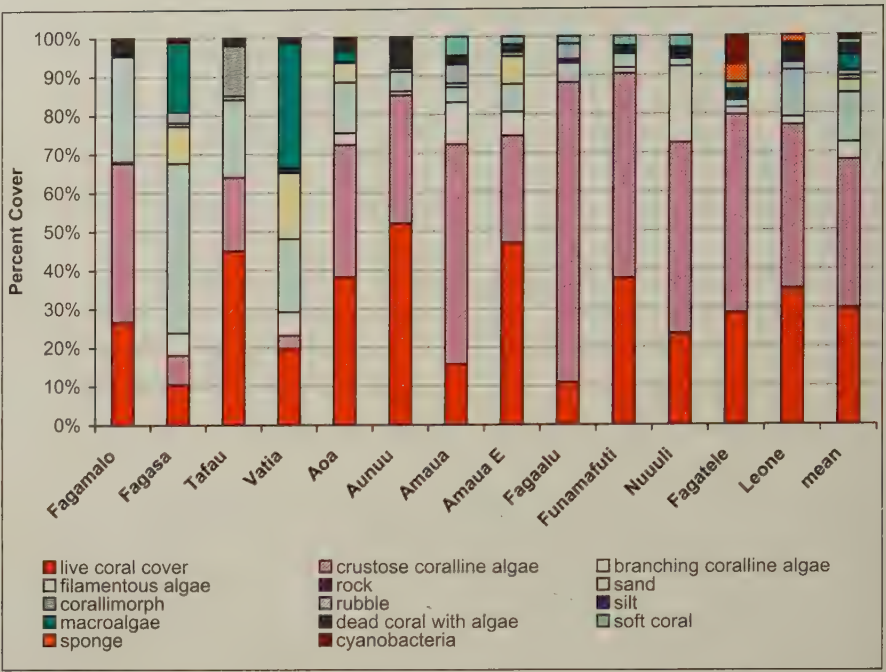


*Figure 10.16. Benthic cover for Tutuila in 2006 at 9 m depth, TMP. Sites are in sequence clockwise around the island, beginning with Fagamalo on the Northwest. The leftmost five sites are on the north side of the island, the remainder on the south (Aunu'u is a separate small island in the southeast). The mean is shown on the far right. Source: Fenner and Carroll, in review.*

Long-term trends in benthic cover were reviewed in Green et al. (1999) and Craig et al. (2005). Mean benthic cover recorded by TMP for Tutuila was essentially unchanged from 2005 to 2006, with live coral cover in the 11 core sites sampled in both years changing by only 0.8% and the largest change of any benthic category being only 3.5% (Figure 10.17).

The Secretariat of the Pacific Community (SPC) Pacific Regional Oceanic and Coastal Fisheries (PROCFish) program reports a "live coral index" which expresses the percentage of all coral which is alive (SPC, 2005). The live coral index for the TMP data was 97% live in 2005 and 93% in 2006. The small decline is due to more careful recording of dead coral covered with algae in 2006. The PROCFish program reported an average of 55% live coral index for 27 sites in six different South Pacific nations. The figure for American Samoa is unusually high for the South Pacific, supporting the view that the coral communities are relatively healthy. Visual estimates of the percent live coral cover in the back reef pools of Tutuila are on the order of 50% for staghorn Acroporids, though near 100% for *Porites cylindrica*.

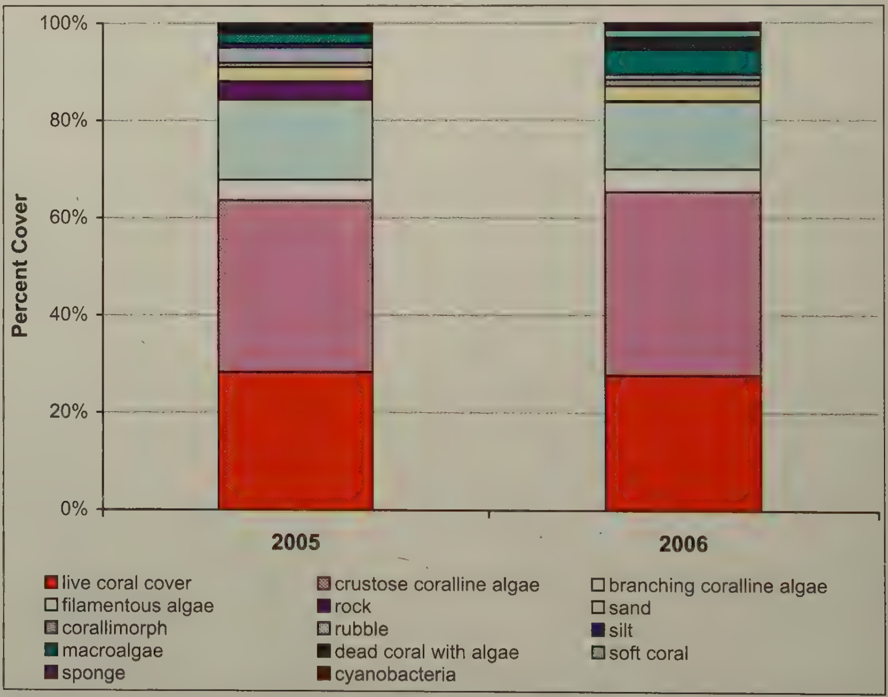


*Figure 10.17. Trends in mean benthic cover for Tutuila from 2005 to 2006 at 9 m depth at the 11 core TMP sites. Source: Fenner and Carroll, in review.*

In 2006, more turf was recorded on the north side of Tutuila (t=3.29, p<0.022), and more CCA was recorded on the south side of the island (t=3.84, p<0.005; Figure 10.18). Similar trends were apparent in 2005 data, in data from ASEPA Biological Criteria Monitoring for 2003 and 2005, and in the Key Reef Species and Coral Disease Monitoring data, despite differences in monitoring site locations. It is apparent that these findings are general to the entire island. Coralline algae thrive best in environments devoid of other algae and sediment (Dawson, 1961; Steneck, 1997; Fabricius and De'ath, 2001). Due to the prevailing easterly winds and orientation of Tutuila, southern reefs experience more wave action that flushes sediments from nearshore areas, providing conditions conducive to the development of CCA.

At many reef slope sites, visible CCA dominate the shallow water, but *Halimeda* calcareous green macroalgae often dominate the substrate between corals lower on the slope. The division between these two zones can be fairly abrupt, occurring over just a few meters. The dividing line in the north appears to be at a shallower depth than in the south; for example this division is apparent at about 5 m depth at Vatia in the north, while at Amaua and Fagaalu in the south the division occurs at about 12 m. It appears that the greater wave surge on the south allows visible CCA to extend into deeper water. It is possible that CCA species that are tolerant of turf algae and sediment may be present under the uppermost biotic layer but were not detected by these methods which focus on the visible biotic cover.

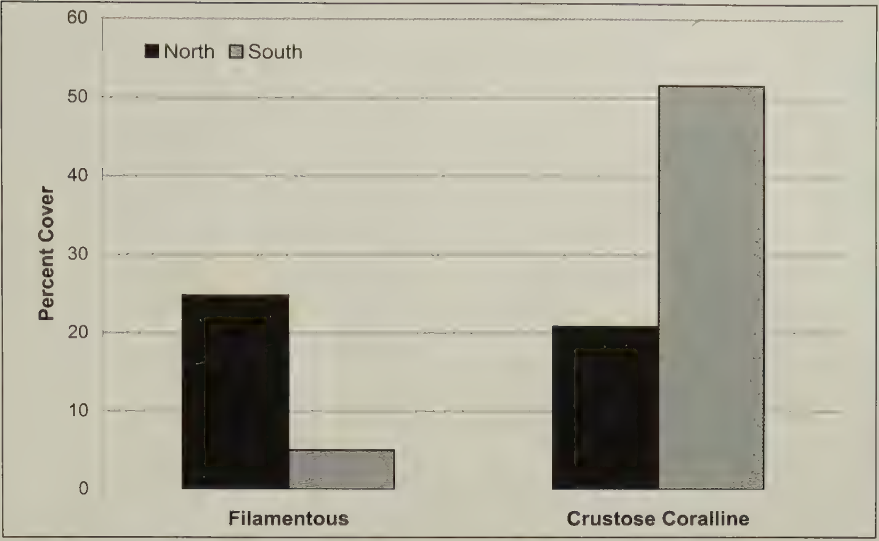


*Figure 10.18. Filamentous and crustose calcareous algae cover on north and south sides of Tutuila at 9 m depth in 2006. Source: Fenner and Carroll, in review.*

Encrusting corals dominate the coral lifeforms at the 11 TMP sites, and were followed in abundance by branching, massive and table corals. Other lifeforms were uncommon. Most monitoring programs have noted the dominance of encrusting corals on Tutuila reef slopes. An encrusting coral in the genus *Montipora,* which is presently being identified to species, was the most common coral species in TMP transects at 9 m around Tutuila, followed by *Porites rus*, *Lobophyllia hemprichii*, and *Pavona varians* (Figure 10.19); *P. varians* is encrusting and *P. rus* colonies are usually plates and/or columns. *L. hemprichii* is submassive and dominates large areas on the southeast side of Tutuila, but is rare elsewhere.

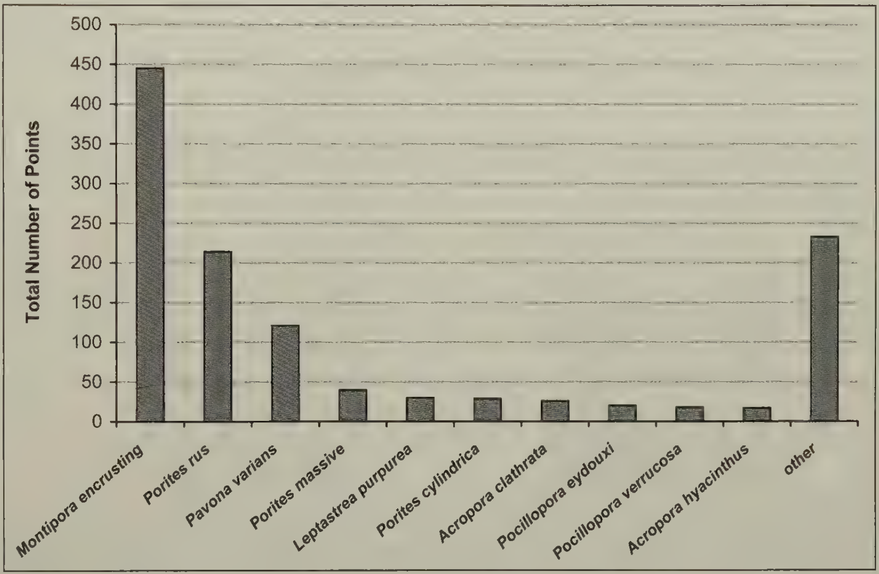


*Figure 10.19. Coral species in TMP transects at 9 m depth. Source: Fenner and Carroll, in review.*

There was a mean of 17.9 coral species per transect in 2006, with a range of 9-29 species. A total of 77 coral species were found along transects at the 11 TMP sites. In roving biodiversity surveys, coral species richness averaged 72 species in 2006, with a range of 62-84 species. A total of 147 coral species were found in 11 biodiversity dives. Encrusting *Montipora* sp. was the most common species followed by *Pavona varians*. The order is slightly different from that in transects, probably due to the greater depth range surveyed in roving biodiversity surveys.

Qualitative observations have also been recorded at TMP sites around Tutuila. Sites on the north side of the island have visible CCA in shallow water which does not extend into deeper water, and a mixed coral community in deeper water. Sites on the south side show two main patterns, mixed coral and coralline algae at all depths, and mixed coral and coralline algae in shallow water with *Mycedium* plates and *Halimeda* algae in deeper water. At a few sites there are monospecific stands of particular species in shallow or medium depths.

The TMP also measured benthic cover on reef flats and compared outer and inner reef flats. Higher coral cover, turf and slightly higher visible CCA was found on the outer reef flat, and more rubble, sponge and sand on the inner reef flat. Outer reef flat averaged 21% coral cover, and inner reef flat averaged 7% coral cover. The reef crest has striking zonation at Nuuuli and at some other sites (e.g., Matuu). In 2007, the Nuuuli reef flat had little living coral and areas in which CCA had been killed by extreme low tides. Approaching the crest, a narrow black band dominated by turf algae was visible, and the outer crest was dominated by living CCA with a few species of small branching corals. Figure 10.20 depicts the increase in CCA and decrease in turf algae as distance from the crest increased.

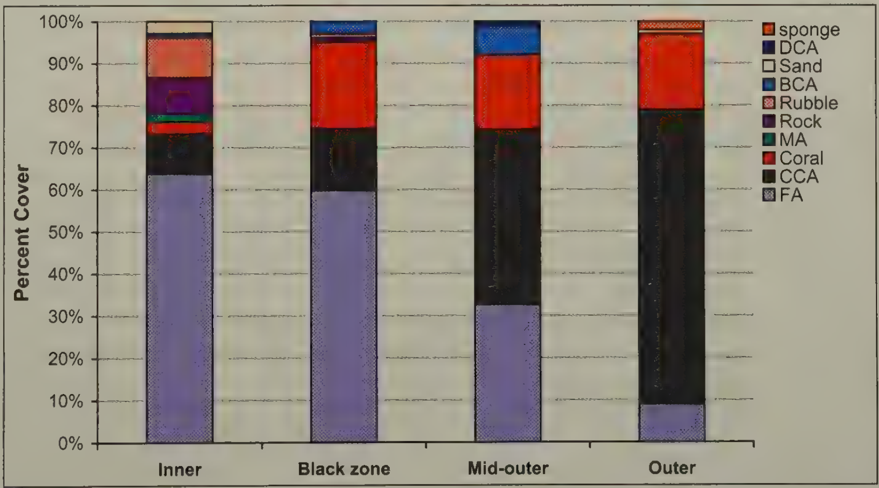


*Figure 10.20. Nuuuli reef crest zonation as recorded during TMP surveys in 2007. DCA=dead coral with algae; BCA=branching coralline algae; MA=macroalgae; FA=filamentous algae. Source: Carroll and Fenner, unpub. data.*

In 2007, a recruitment pulse of the table coral *Acropora hyacinthus* was observed at several sites around Tutuila, from the outer reef flat down to about 4 m depth. Recruits ranged from about 5 to 20 cm diameter, and were 1-4 cm tall. They all appeared to be from a single recruitment event, perhaps about two years earlier. If they survive, they may considerably increase coral cover at some sites and may even become dominant in a few areas. Table corals were a major component of reef communities in American Samoa before the COTS outbreak in 1978 and can form a climax community due to their ability to outcompete other corals and avoid contact with mesenterial filaments, sweeper tentacles and sweeper polyps.

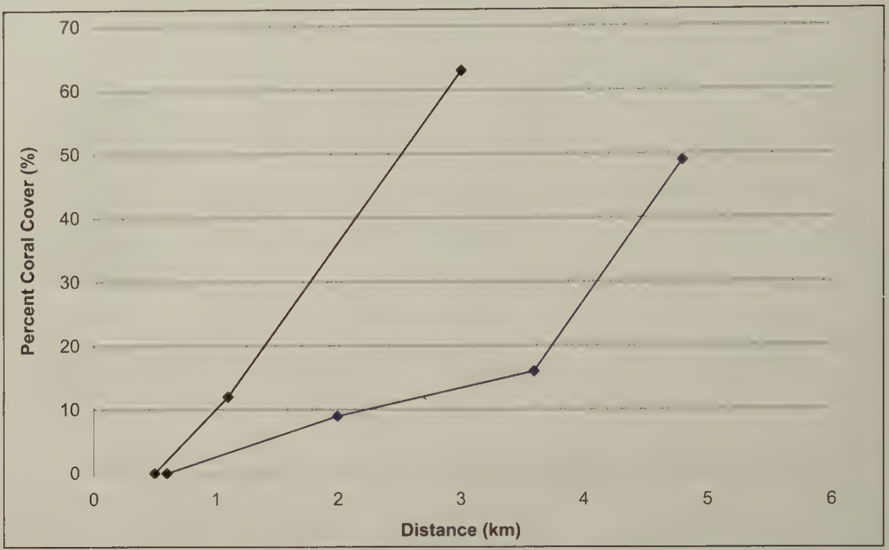


*Figure 10.21. Coral cover on reef flats in the harbor by distance from the head of the harbor; left line south side (black), right line north (blue). Source: Carroll and Fenner, unpub. data.*

Reefs in Pago Pago Harbor have been dredged, filled or built over, and subjected to a variety of other disturbances, such as nutrients from the canneries and sediment runoff. Small areas of excellent reef flat that appear undisturbed remain near the mouth of the harbor at Utelei and Onosesopo. Transects were run on outer reef flats at these two locations and other locations farther inside the harbor, and on a rock wall in Fagatogo. Observations were also made at locations farther inside the harbor. Coral cover was very high near the mouth of the harbor, but decreased to zero near the head of the harbor (Figure 10.21).

Small oysters, *Sacrostrea cucculata*, form a band on hard surfaces in the intertidal zone in the harbor. They show the opposite gradient, with high densities near the head of the harbor and low densities at the mouth of the harbor. Oysters are filter-feeding bivalves, and may be a good bioindicator for plankton populations. Secchi disc readings in the harbor show a gradient with turbid, green water near the head of the harbor, and clear, blue water near the mouth of the harbor. Recently, there have been large algae blooms in the water at the head of the harbor, turning the water reddish brown. The blooms were produced by the dinoflagellate, *Ceratium* cf. *furca* (identified by Fred Brooks), and do not appear to be toxic. The turbid water and dinoflagellate blooms near the head of the harbor are likely to be bioindicators of nutrient input into an area with little flushing to the open ocean. Mayor's (1924) pioneering paper indicated that coral reefs extended to near the head of the harbor a hundred years ago. However, it appears that conditions are presently not conducive to coral growth there.

*Bleaching*

Bleaching has been monitored by the TMP in two back reef lagoon pools on Tutuila from December 2003 to the present. The percentage of colony surface with signs of bleaching of staghorn corals (three species of *Acropora*) in two back reef lagoon pools on Tutuila (Airport and Alofau) were estimated based on hour-long timed swims every 2-4 weeks, beginning in December 2003. Incidental observations were also made on reef slopes.

Bleaching has been recorded in back reef pools in *Acropora* every summer starting in 2004, but only scattered light bleaching of *Montastrea curta* and *Pocillopora* spp. has been seen on reef slopes, and only in 2005 and 2007. The back reef pools are dominated by *Porites cylindrica* and the staghorn *Acropora muricata* (=formosa), with the staghorns *A. pulchra* and *A. nobilis* less common. All *Acropora* species were observed to bleach in the pools, plus *Millepora dichotoma*, and one small patch of *Porites cylindrica*. Temperature loggers placed in some of the back reef pools revealed maximum temperatures of about 32°C reached for a half hour in most of the pools, but one (Fagaitua) reached a maximum of 34.9°C for half an hour one day in 2005. Staghorns there were mildly bleached at the time. Satellite SST measurements, which are produced globally on a 0.5 degree grid twice each week by NOAA's Coral Reef Watch, were approximately 30°C at that time. The course of bleaching in the Airport pool and ocean SST's can be seen in Figure 10.6. There is a striking correlation between the two. Reports of mass bleaching in 2002 and 2003 plus the presence of dead staghorns suggest that staghorns in the back reef pools have bleached every summer since at least 2002, and possibly earlier. A three-week stormy period with lowered temperatures and light produced a notch in the curve for 2006 on February 15. The staghorns are now spending as much time bleached as unbleached, but there has been little colony mortality in the last four years. On Ofu, the natural lagoon pools regularly reach high temperatures midday at low tide on sunny days, yet a high diversity of corals live there (Craig et al., 2001). Ongoing research is being completed to investigate coral survival in such extreme temperatures (C. Birkland, L. Smith and D. Barshis, personal comms.).

### *Coral Disease Monitoring Program (CDMP)*

This program monitors seven sites around Tutuila annually, with two 25-m tapes laid on depth contours at 5-18 m, with most at 6-10 m. Data collection began in 2004. Benthic categories are recorded with the point-intercept technique. Similar transects were conducted in the Ofu back reef pools in 2005 and on six sites on reef slopes around Ofu-Olosega in 2006 (Aeby et al., 2006).

*Results and Discussion*

The CDMP found 37.4% coral cover on Tutuila, 16.8% coral cover on Ofu-Olosega, 32.6% CCA cover on Tutuila and 48.6% CCA cover on Ofu-Olosega in 2006. The disease monitoring program has recorded CCA cover over time, and when combined with historical records from Birkeland et al. (1987), shows a decrease in CCA over time (Figure 10.22). Sites within Fagatele Bay show the same trend, and each of seven sites in the disease monitoring program show the same trend, as does the PIFSC-CRED program from 2004 to 2006.

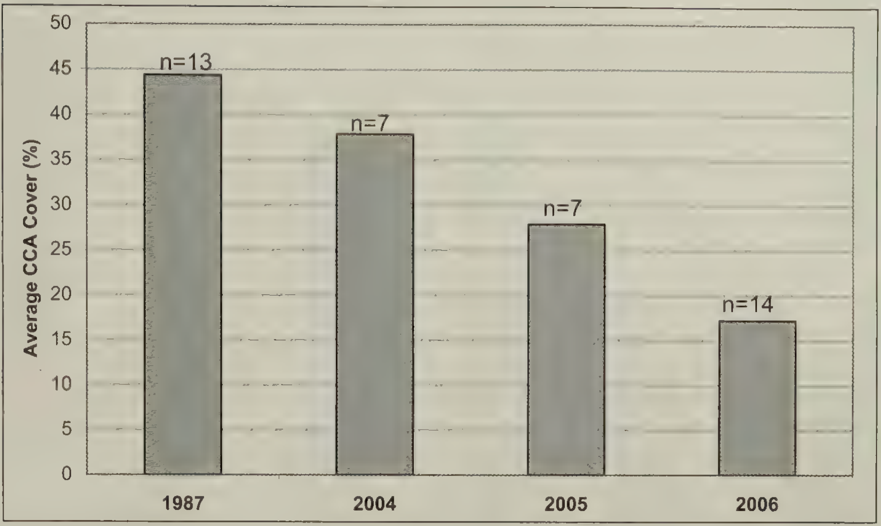


*Figure 10.22. CCA cover averaged for Tutuila sites, over time. The number of sites is indicated above each bar. Source: CDMP and Birekand, 1987.*

### DMWR's Key Reef Species Program

This program conducts annual monitoring at 24 permanent sites around Tutuila. The benthic assemblage is recorded from four replicate 30 m benthic transects at 10 meters depth using an underwater video taken 0.5 m from the bottom. Fifty frames are grabbed from each transect and benthic cover is identified to functional categories at 12 randomly assigned points per frame (Sabater and Tofaeono, 2006).

*Results and Discussion*

Hurricanes generally impact the north shore of Tutuila more intensely than the south side. On the south side, fringing reef is nearly continuous and found on both points and in bays (NOAA, 2005). On the north side, fringing reefs are found only in bays and not on points. The TMP currently only monitors reefs in bays, and not communities on points, but the KRSP monitors points, as well as bays. Points have communities of scattered small corals on basalt, generally with no carbonate accumulation, except in deep water. KRSP data shows that coral cover is higher in bays than points on the north side, but does not differ between points and bays on the south side (Figure 10.23). It is likely that hurricanes remove corals from points on the north side, allowing reef accumulation only in bays, as in Hawaii (Grigg, 1998).

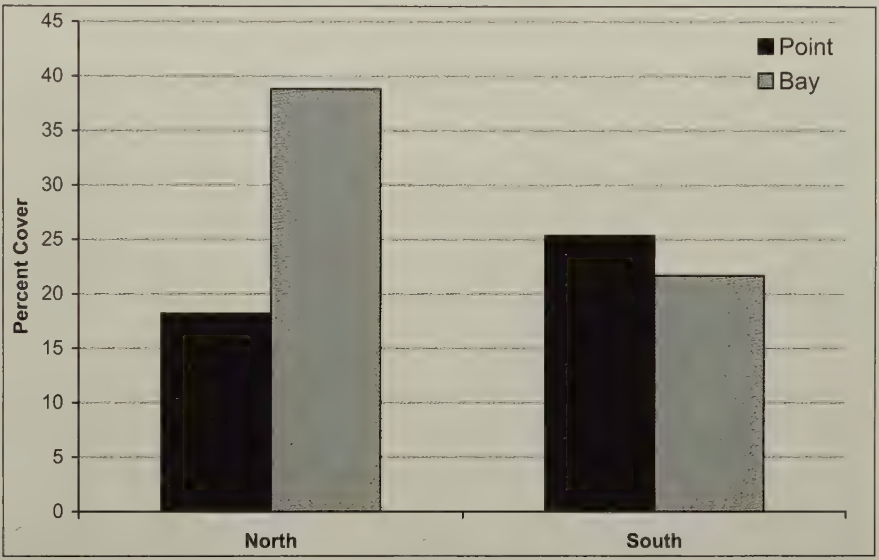


*Figure 10.23. Coral cover compared between bays and points on the north side and south side of Tutuila in 2005, KRSP. Source: Sabater and Tofaeono, 2006.*

### Reef Assessment and Monitoring Program of the Coral Reef Ecosystem Division (PIFSC-CRED)

This program records benthic data on each island in American Samoa biannually, starting in 2002 and with increasing numbers of sites over the years (a total of 62 sites in 2006). At each site, two 25-m tapes are laid at 12-15 m depth, and benthic cover recorded using the point-intercept method (Brainard et al., in review). Coral disease prevalence was also recorded based on a methodology developed, tested and implemented in the NWHI by G. Aeby (Friedlander et al., 2005).

Quantitative algal monitoring continued during 2006 in an effort led by PIFSC-CRED and supported by several partner agencies in American Samoa. Twenty-two sites were surveyed around Tututila, 18 sites were surveyed around the Manua islands, 10 sites were surveyed at Rose Atoll and eight sites were surveyed at Swains Island. Continued use of the algal monitoring protocol established in 2003 (Preskitt et al., 2004) assured uniformity of data sets for statistical analyses.

*Results and Discussion*

Figure 10.24 shows benthic cover from the PIFSC-CRED program for all the islands of American Samoa. As can be seen in the figure, on most islands CCA had the highest cover, followed by coral. Coral cover was highest on Swains, lowest on Rose, and intermediate for Tutuila, Ofu-Olosega and Tau. CCA was lowest on Tau and Swains.

The PIFSC-CRED program records the genera of corals on each island, as shown in Figure 10.25. *Montipora* is the most important genus on most islands and shows a slight decrease towards the east in the archipelago. Rose and Swains, the two old, low atolls, have much higher abundances of *Pocillopora* than the young high volcanic islands. The number of genera of coral is also recorded by PIFSC-CRED for each island. Figure 10.26 shows the number of genera on each island. The two old low islands, Swains and Rose, have much lower coral generic diversity than the young high islands.

Of the 62 sites visited, 38 (61%) revealed disease, and five disease states were enumerated: bleaching, skeletal growth anomalies, tissue loss/white syndrome, black band disease and "other lesions" (including algal irritations and hyperpigmentations). Diseases were observed on 14 coral genera, with *Montastrea*, *Favia*, *Montipora*, *Porites*, *Astreopora* and *Acropora* exhibiting the greatest frequency of occurrence (93% of cases), while *Favia*, *Coscinaraea* and *Leptoria/Platygyra* showed the greatest disease prevalence. Rose Atoll exhibited both the greatest occurrence of coral disease (67% of cases) as well as the highest mean overall prevalence (0.99 ± 0.6%; mean ± SE). Two northerly fore reef sites exhibited the greatest overall prevalences values (4.2 and 4.9%). This was due to a large number of cases of "other lesions" mainly on colonies of *Montastrea* cf *curta* and *Favia stelligera*. Other coral lesions at Rose involved bleaching, growth anomalies, and white syndrome; the above mentioned diseases were detected on colonies of *Pocillopora*, *Astreopora* and *Acropora*, respectively (Figure 10.9).

Of sites visited around Tutuila, fifty-five percent contained disease. The overall mean prevalence for the island was 0.13 ± 0.04%. Three north and northwestern sites exhibited the greatest prevalence of disease (range 0.1–0.27%). Overall, the most common disease state was "other lesions" particularly algal irritations with pigmentation responses (48%), which was observed predominantly on *Montipora* and *Porites*, but also *Astreopora* and *Leptoria*. Skeletal growth anomalies were the second most common type of lesion (31%), with prevalence values as high 0.24% at a northerly site west of Massacre Bay. Skeletal growth anomalies were mainly detected on *Acropora abrontanoides*, but also on *Astreopora*, and *Favites*. Other types of coral disease states present around Tutuila included mild bleaching, white syndrome (all cases on colonies of *A. cytherea*), as well as one case of black band disease on *Porties* cf. *lobata* (Figure 10.27).

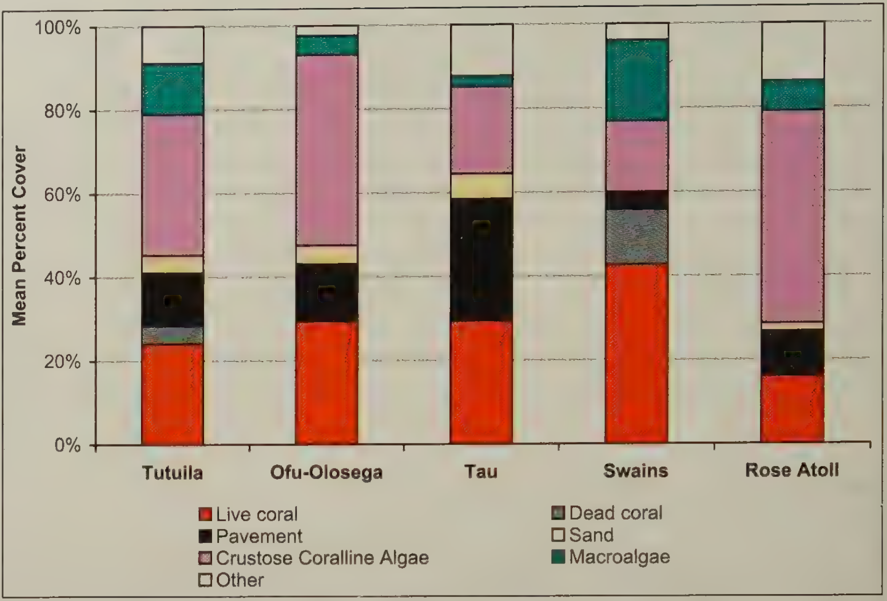


*Figure 10.24. Benthic cover on each of the islands of American Samoa in 2006. Source: Brainard et al., in review.*

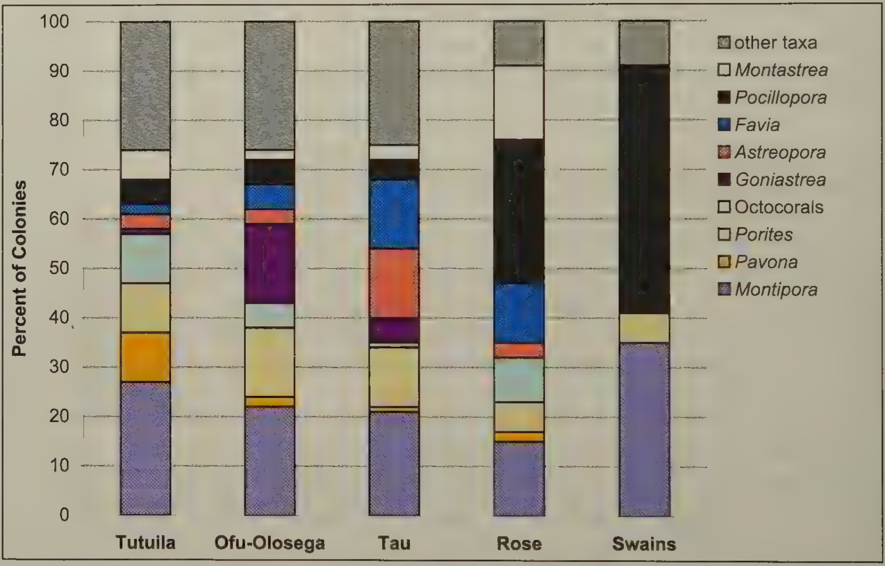


*Figure 10.25. Coral genera by island in 2004. Source: Brainard et al., in review.*

Mean overall disease prevalence at Ofu-Olosega amounted to 0.06 ± 0.03% with mild, focal bleaching and growth anomalies being the only two afflictions observed to affect corals within the 12 sites visited (Figure 10.9). Prevalence of bleaching did not exceed 0.16% and was most commonly observed on *Platygyra*, *Leptoria*, *Montipora* and *Porites*. Skeletal growth anomalies exhibited a mean prevalence of 0.01% at one site only on the east-facing shore, where all cases were detected. All cases of skeletal growth anomaly occurred on colonies of *Acropora abrontanoides*.

Of the nine sites surveyed at Tau, eight (89%) contained disease. Overall mean prevalence was 0.1 ± 0.03%, and diseases were detected at all sites, except one location on the north-facing shore. Skeletal growth anomalies were the most prevalent disease state (range: 0.02–0.24%) with *Astreopora* and *Montipora* exhibiting the totality of cases. Mild, focal bleaching was also detected at Tau with low mean overall prevalence (0.03%) and affected *Monitpora*, *Porites*, *Pocillopora* and *Montastrea*. Finally, the estimated mean overall prevalence for Swains amounted to 0.04 ± 0.03%. Only growth anomalies, other lesions and bleaching were detected on Swains. Growth anomalies and other lesions were observed on *Porites* spp., and bleaching was observed on *Fungia*.

Although disease states are observed on corals in the American Samoa archipelago, prevalence values are comparable to the Hawaiian archipelago and Pacific Remote Island Areas (PRIA). PIFSC-CRED surveys indicated that patterns of disease distribution and abundance varied considerably within and among islands. Patterns of disease occurrence and prevalence across the coral taxa also indicated that a few genera may be disproportionately targeted by disease, suggesting that the ecological impacts of disease may be more severe in populations of uncommon or rare corals.

PIFSC-CRED currently has two analyses underway for algal data from American Samoa. In the first, spatial and temporal variability of the relative abundance of macroalgae (RAM) at the genus level was examined at all islands between 2004 and 2006. Crustose calcareous red algae, turf algae and the chlorophyte *Halimeda* were ubiquitous, while other algal genera were representative of specific locales. The chlorophyte *Microdictyon* was only found at Rose and Swains, and the siphonous green alga *Rhipilia* only occurred at Swains. Tutuila showed the highest macroalgal diversity, likely because of higher habitat diversity. RAM varied noticeably among sites at a single island, also likely because of habitat diversity. RAM also varied temporally between 2004 and 2006, especially at Tau, Rose and Swains. This temporal change resulted from hurricane effects in 2005, as well as to the continued decrease in pollution after the cleanup of a shipwreck at Rose Atoll. In the second ongoing analysis, similarities in benthic community populations among sites from Rose Atoll will be spatially and temporally compared using multivariate statistical analysis.

Figure 10.28 shows the relative abundance of the different algal genera on each of the islands, for 2004 and 2006. CCA declined in relative abundance on all three of the high islands from an average of 33% to 20%, but not on the atolls.

An article appearing in *American Scientist* (Vroom et al., 2006) compared percent cover of macroalgal, turf algal, crustose calcareous algae and coral populations at eight islands across the Pacific, including Swains Island and Rose Atoll from American Samoa. Of all islands sampled, Swains Island exhibited the highest percent cover of live coral colonies in conjunction with some of the highest macroalgal populations. Rose Atoll was notable for containing the highest percent cover of red crustose calcareous algal populations, a historically noted phenomenon that gives the island its name.

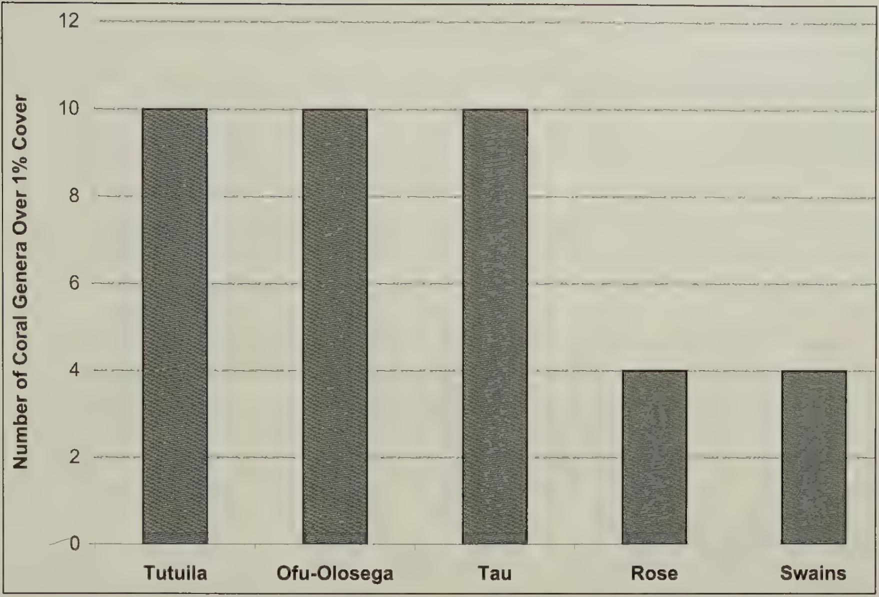


*Figure 10.26. Number of coral genera accounting for >1% cover by island in 2004. Source: Brainard et al., in review.*

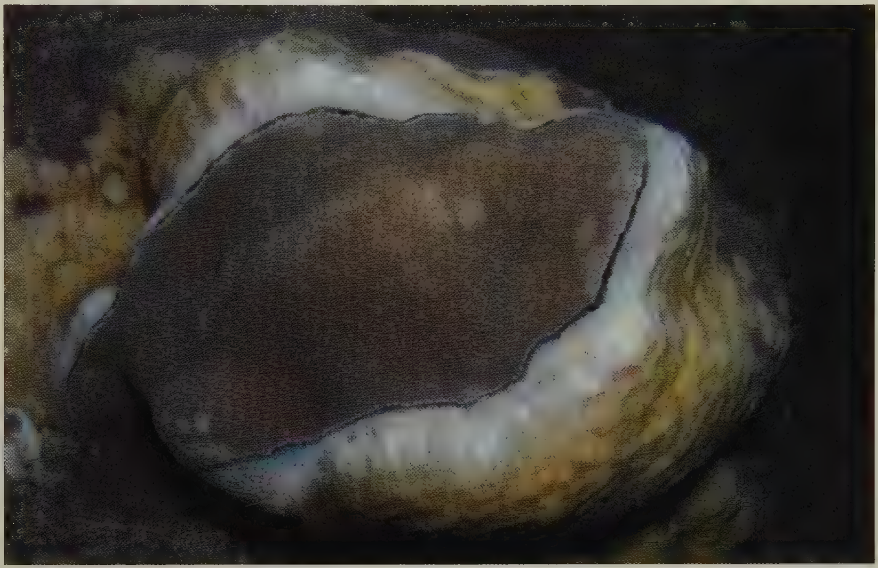


*Figure 10.27. Black band disease on* Porites *at a northwest fore reef site on Tutuila. Photo: B. Vargas-Angel.*

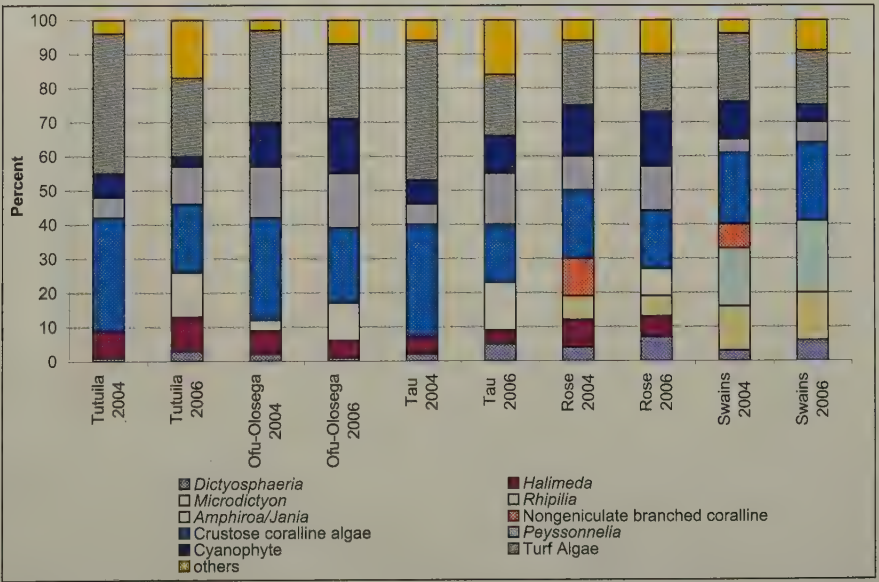


*Figure 10.28. Relative abundance of algal genera by island in 2004. Source: Brainard et al., in review.*

## Coral Reef Biological Criteria Monitoring of the American Samoa Environmental Protection Agency

This study monitors sites on Tutuila annually, beginning in 2003 with six sites. In 2005 two of those sites were repeated and six additional sites surveyed. At each site video is recorded of three belt transects 0.5 m wide and 50 m long at 9-11 m depth. Benthic cover is recorded under six randomly placed dots on a still image every five seconds on the tape (Houk et al., 2005).

*Results and Discussion*

This study found an average of 24.3% live coral cover, 47.2% CCA, 12% turf and 8.6% macroalgae in 2007 (see Water Quality Section for more discussion of this study).

## Long-Term Monitoring Program of the Fagatele Bay National Marine Sanctuary

This program surveys benthic communities in Fagatele Bay National Marine Sanctuary in a 30 m long transect on a depth contour, with substrate cover recorded on a point each 2 m, and also at one point 2 m to each side of the transect line, in 2004. This was done at 3, 6, 9, 12 and 18 m depths at four sites, and 9 and 12 m at two additional sites (Green et al., 2005). In 2002, the program expanded surveys to sites throughout the volcanic islands of the territory (Fisk and Birkeland, 2002; Green, 2002) and recorded sizes of corals in seven logarithmic size categories within 0.5 m x 20 m belt transects in 2002 (Fisk and Birkeland, 2002).

*Results and Discussion*

Depth zonation at some sites appears to be fairly strong, with visible CCA in shallow water and *Halimeda* green macroalgae in deeper water. The only study to investigate depth zonation quantitatively was Green and Mundy (2005) in Fagatele Bay. Fagatele Bay is unusual in that the reef does not end in a shelf but rather continues into deeper water. Figure 10.29 shows benthic cover by depth from the Green study. Coral cover did not vary with depth, and CCA decreased only at the deepest survey sites (18 m).

Survey results from each of the volcanic islands in 2002 are summarized in Figure 10.30. Aunuu was found to have a higher coral cover than Tutuila, an observation supported by the TMP as shown in Figure 10.30. Green (2002) had three sites on Aunuu, while the TMP only had one. Ofu-Olosega had much lower coral cover than Tutuila, Aunuu, Ofu Lagoon and Tau.

Fisk and Birkeland (2002) repeated the measurements of coral colony sizes that Mundy (1996) made on Tutuila, Ofu-Olosega and Tau. The average colony size increased during the 1995-2002 period on Tutuila (Figure 10.31) and Tau, but decreased on Ofu-Olosega (Figure 10.32). These trends can be seen in their data for most individual sites as well. Fisk and Birkeland (2002) point out that the corals of Tutuila and Tau were recovering from Hurricane Ofa in 1990 and Hurricane Val in 1991. This could explain why colony sizes were increasing there. They also point out that Ofu-Olosega had a moderate chronic infestation of COTS during this period (D. Fisk, pers. comm.) and suggest that because small parts of targeted colonies often remained following COTS predation on a colony, their feeding patterns reduced the number of larger colonies and increased the number of small colonies.

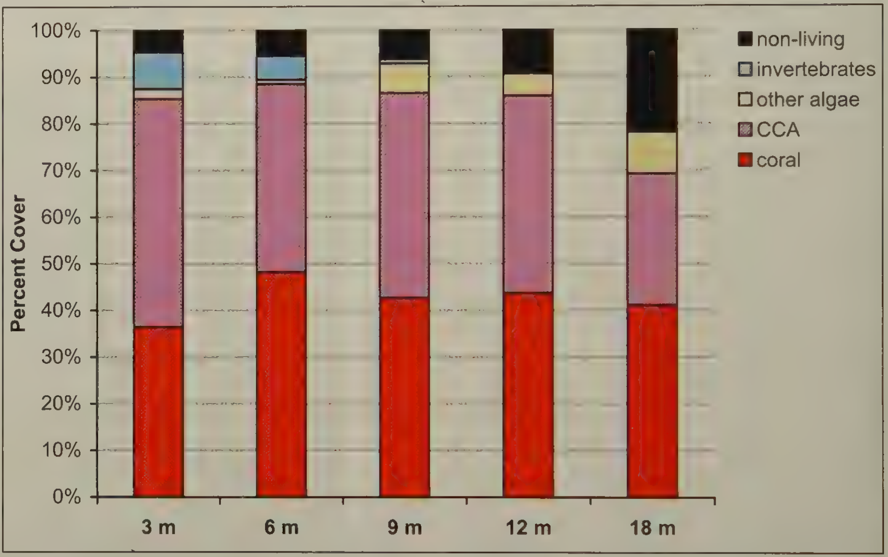


Figure 10.29. Benthic cover by depth at Fagatele Bay. Source: Green and Mundy, 2005.

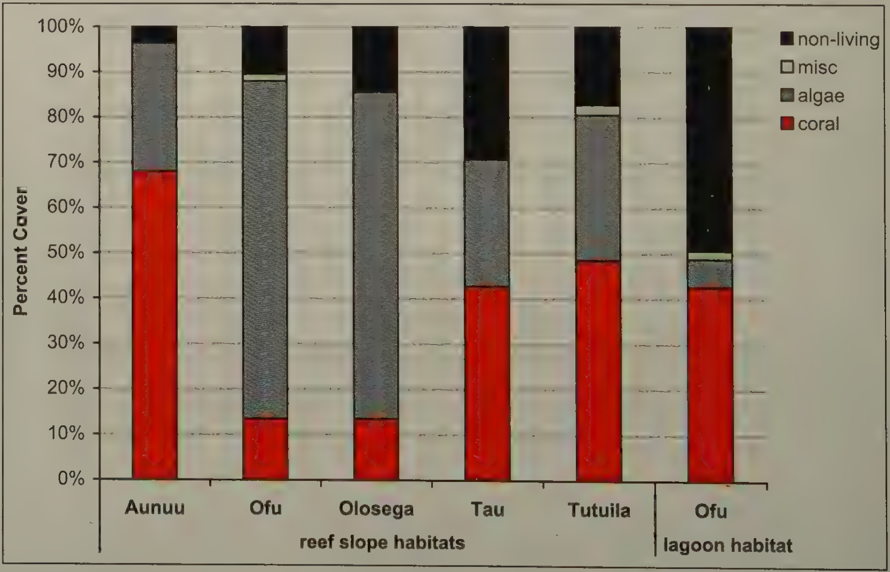


Figure 10.30. Benthic cover on the volcanic islands of American Samoa. Source: Green, 2002.

### *Reef Flat Surveys*

Reef flats and back reef pools were surveyed in 2003 as part of a master's thesis by Andrews (2004). Five 25-m tapes were laid and benthic cover recorded with the point-intercept technique at each of 11 sites. In another study, reef flats/pools were surveyed at Ofu Village, Toaga on south Ofu, and Olosega Village in 2006 by Garrison et al. (2007). Substrate categories were recorded using the point-intercept method, with tapes laid perpendicular to shore from crest to shore.

*Results and Discussion*

Andrews (2004) found that coral cover varied greatly by location as shown in Figure 10.33, but averaged about 45%.

In the study by Garrison et al. (2007) three sites on Ofu-Olosega were studied, and benthic cover was found to be composed primarily of turf (filamentous) algae, rock and rubble, with live coral cover of 6-23%.

### Comparisons and Conclusions

Several different programs have recorded benthic cover on the reef slopes of Tutuila in recent years. These studies differ considerably in their objectives, methods and site locations. For instance, TMP uses point-intercept while KRSP uses video, and these two programs have no sites in common. In spite of these differences, the two programs produced very similar means for percent coral cover (Figure 10.34). Some differences between the results of different programs result from the use of different categories for recording benthic cover. In particular this applies to differences in categories used for algae. Nevertheless, there appears to be broad agreement that CCA is an important benthic component, and that live coral cover averages about 22–34%. The mean live coral cover for these six studies was 28%. The SPC PROCFish program reported an average live coral cover on reef slopes of 25% for 27 sites in six South Pacific countries (SPC, 2005). The Main Hawaiian Islands have an average of 20.8% coral cover (Friedlander et al., 2005), fore reef sites in the NWHI averaged 28.2% (Friedlander et al., 2005), the Federated States of Micronesia averaged 30% (Hasurmai et al., 2005), the Marshall Islands averaged about 62% (Pinca et al., 2005) and the Commonwealth of the Northern Mariana Islands averaged 21%. Bruno and Selig (2007) reported average cover for the South Pacific of about 23–24%, and for the Indo-Pacific from Indonesia to French Polynesia of 22.1%. Thus mean live coral cover on Tutuila was higher than in most other areas in the region.

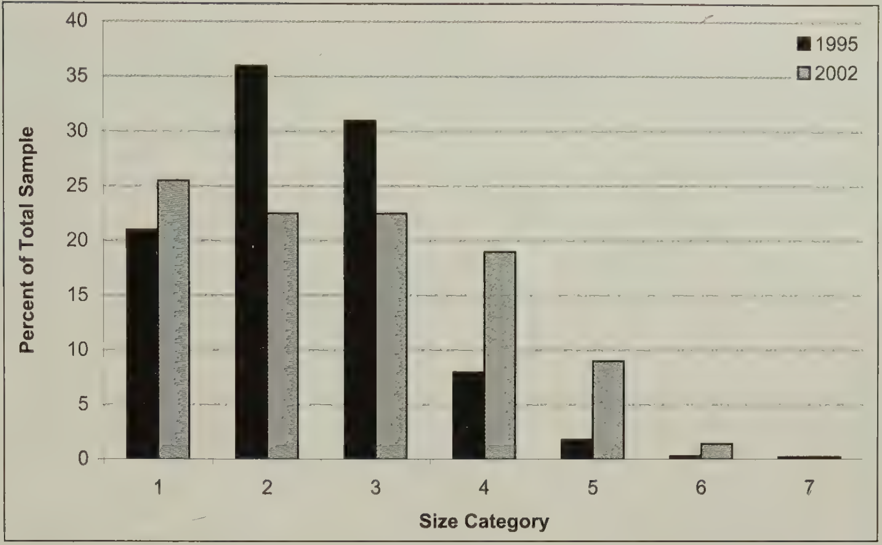


*Figure 10.31. Coral colony size distributions for all coral species for 1995 and 2002 for Tutuila Source: Fisk and Birkeland, 2002; Mundy, 1996.*

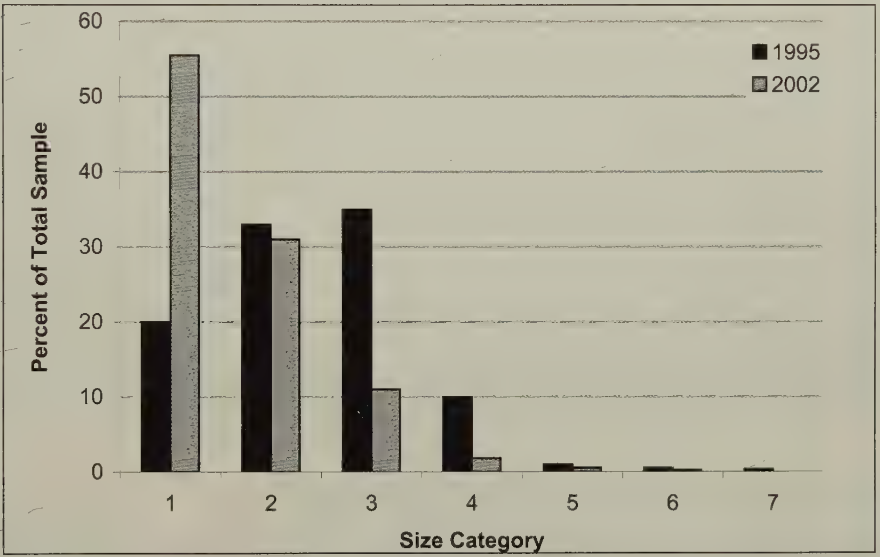


*Figure 10.32. Coral colony size distributions for all coral species for 1995 to 2002 for Ofu-Olosega. Source: Fisk and Birkeland, 2002; Mundy, 1996.*

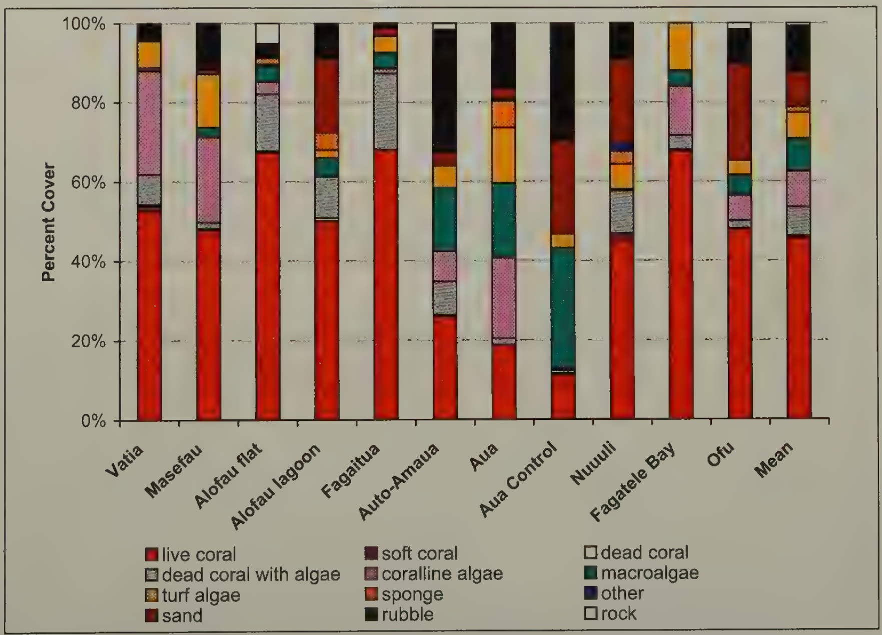


*Figure 10.33. Benthic cover on reef flats of Tutuila. Source: Andrews, 2004.*

The differences between Ofu-Olosega and Tutuila were much smaller in the PIFSC-CRED study than reported by Green (2002) or the CDMP. Green's study found that Tutuila had nearly 50% coral cover in 2002, while the PIFSC-CRED program found only about 23% cover in 2006. The first is higher than other studies have found, and the second was lower. It is not clear whether this is due to selection of different sites or to changes over time. The Green study also reported a higher coral cover on Tau than the PIFSC-CRED study. On the other hand, the Green study reported a much lower coral cover on Ofu-Olosega than the PIFSC-CRED study. This difference is likely a result of temporal changes and reflects a real increase in coral cover as the reefs recovered from chronic COTS predation.

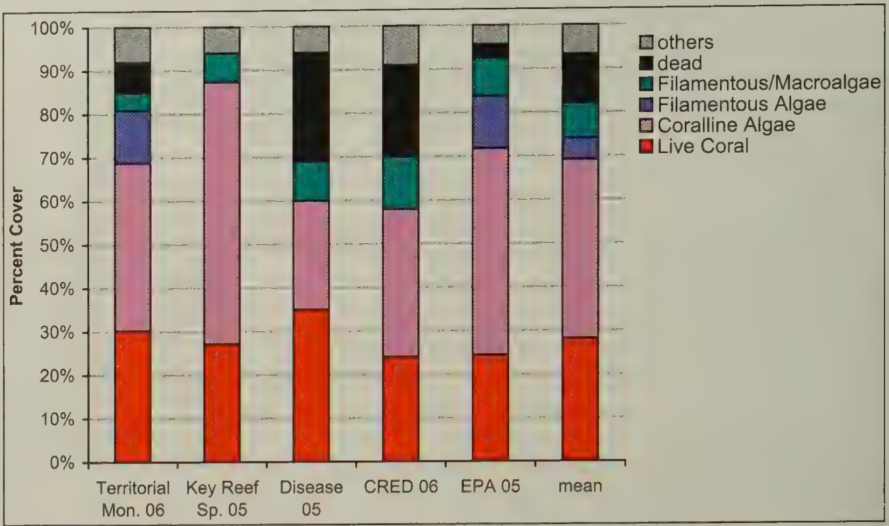


*Figure 10.34. Benthic cover on reef slopes of Tutuila reported by five studies. Sources: Fenner and Carroll, unpub. data; Sabater and Tofaeono, 2006; Aeby et al., 2006; Brainard et al., in review; Houk, 2005.*

The reefs of American Samoa are notable for having relatively abundant CCA. CCA grow best when they are clean of sediment and other algae. In American Samoa, CCA are most abundant near the reef crest (outer reef flat and the upper reef slope) most likely because the wave surge near the crest keeps them clean of sediment. In addition, fish populations in these habitats are dominated by herbivorous fish that keep CCA surfaces clean of overgrowing algae. For most of the year, wave surge is greater on the south side of Tutuila than the north, and this may explain why visible CCA extend farther down the reef slope and are more abundant on the south side than the north. Some coralline algae attract coral larvae to settle, so the large amounts of coralline algae may have aided coral recovery following the COTS outbreak of 1978 and hurricanes in 1990 and 1991. Two studies (CDMP and PIFSC-CRED) have found declining populations of CCA, but another (TMP) found no decline. A decline in CCA may be a cause for concern, depending in part on what replaces it. It appears that the coral populations on Ofu-Olosega are still recovering from moderate but persistent predation by COTS, which now appear to be near background levels. In several ways (e.g., coral and algal genera; invertebrates) the two atolls, Rose and Swains, stand out as different from the high volcanic islands. Although they are much older, it seems more likely that runoff from high islands and/or the presence of people may be responsible for differences between the high islands and the atolls.

## ASSOCIATED BIOLOGICAL COMMUNITIES

### *Status of Coral Reef Fish Populations: Fishery-Independent Ecological Surveys and Monitoring*

Quantitative assessment of coral reef fishes began in American Samoa as early as 1977 when Wass (1982) conducted a study on the community structure of reef fish at 63 sites around the island of Tutuila. Since that time, a number of other fishery-independent surveys involving underwater visual census (UVC) have been conducted by various local agencies, as well as by visiting off-island researchers. Starting in 2005, regular annual monitoring of reef fish populations has been conducted under the TMP (with funding from NOAA's National Coral Reef Ecosystem Monitoring Program) and the Key Reef Species Program, both of which are located within the DMWR. PIFSC-CRED began conducting biennial surveys around all islands of American Samoa in 2002, and the results are presented separately below.

With the exception of PIFSC-CRED data, all available data from the various studies were compiled in order to review, compare and describe the current status of coral reef fishes in American Samoa. Table 10.7 shows the various field methods used to collect data including the types of methods used, the number of sites surveyed, the number of replicates per site, and the transect dimensions.

Studies which employed UVC techniques predominantly used belt transects to document diurnal non-cryptic fish assemblages, although transect dimensions varied in length and width. Some programs also targeted specific assemblages while others were more inclusive. For example, the TMP focuses on all diurnal reef fishes while ignoring nocturnal and cryptic species; Page (1998) focused on parrotfishes; and the Key Reef Species Program monitors only fish species that are targeted as a food source in American Samoa. Also, while some programs examined temporal trends in fish abundance and biomass (Green, 2002; Green et al., 2005; Fenner and Carroll, in review), others focused on spatial patterns (Wass, 1982; Green, 1996; Sabater and Tofaeono, 2006, 2007).

#### *Variation in community composition over time*

The reef fish community structure study conducted by Wass from 1977-1979 showed relative dominance (biomass and abundance) of damselfish (Pomacentridae), surgeonfish (Acanthuridae) and parrotfish (Scaridae) for most sites and habitat types around Tutuila (Wass; 1982, unpub. manuscript). The bristletooth surgeonfish (*Ctenochaetus striatus*) was the

Table 10.7. Fishery-independent surveys conducted in American Samoa from 1977 to 2007. Source: DMWR.

| STUDY | PROJECT | YEAR | AVAILABLE DATA | METHOD USED | DEPTH | # OF SITES | REP'S/ SITE | TRANSECT/ SURVEY DIMENSION |
|---|---|---|---|---|---|---|---|---|
| Wass (1982) | Fish community characterization | 1977-1979 | Abundance, biomass, and species composition of diurnal fish | Belt transect | 4-15 m[a] | 63 | 1<br>5 | 100 x 2 m[b]<br>20 x 2 m |
| Green (1996) | Status of coral reefs of the Samoan archipelago | 1996 | Abundance, biomass, and species composition of diurnal fish | Belt transect | 1,5,10,20 m | 18 | 5 | 50 x 3 m |
| Green (2002) |  | 2002 |  | Belt transect | 10 m | 18 | 5 | 50 x 3 m |
| Page (1998) | Ecology, biology and fishery of parrotfishes | 1996-1998 | Abundance, biomass, species composition, | Belt transect | 3,10,20 m | 26 | 5 | 50 x 5 m |
| Green et al. (2005) | Fagatele Bay National Marine Sanctuary Monitoring Program | 1977-2004 | Abundance, biomass, and species composition of diurnal fish | Belt transect | 12,6,9m[c]<br>3,6,9, 12,18 m | 3<br>1 | 3<br>6 | 100 x 2[d]<br>30 x 2 m |
| PIFSC-CRED ongoing | American Samoa Reef Assessment and Monitoring Program | 2002-2006 | Abundance, biomass, and species composition of diurnal fish | Belt transect | 10-15 m | 76[f] | 3 | 25 x 4 m[g], 25 x 2 m[h] |
|  |  |  |  | Stationary point count[i] | 10-15 m | 76[f] | 4 |  |
|  |  |  |  | Towed-diver survey[j] | 15 m | n/a | n/a | 10 m radius n/a |
| Whaylen and Fenner (2006); Fenner and Carroll (*in review*) | American Samoa Territorial Monitoring Program (ASCRMP) | 2005 | Abundance, biomass, and species composition of diurnal fish | Stationary point count | 10 m | 11 | 6 | 7.5 m radius |
|  |  | 2006 |  | Belt transect | 10 m | 11 | 6 | 30 x 10 m[k], 30 x 5 m[l], 30 x 2 m[m] |
| Sabater and Tofaeono (2006) | Key Reef Species Program | 2005 | Abundance, biomass, and species composition of targeted fish species | Belt transect | 10 m | 24 | 3-4 | 30 x 5 m |
| Sabater and Tofaeono (2007) |  | 2006 |  | Belt transect | 10 m | 20 | 3-4 | 30 x 5 m |

A: Depth varies depending on the habitat being surveyed
B: Belt area varies between habitat types and transect orientation
C: Depth shown are for Fagatele Bay, Sita Bay and Cape Larsen, respectively
D: Transect area for years prior to 2004; later surveys used 30 x 2 m transect area
E: Belt transect used for quantifying relatively small bodied and abundant fish
F: The number of sites successfully surveyed varies between years. Numbers show total number of monitoring sites.
G: Transect dimension used to survey fish ≥20 cm TL
H: Transect dimension used to survey fish < 20 cm TL
I: Stationary point count for quantifying relatively larger and agile fish species
J: Towed-diver survey was used for quantify large bodied (>50 cm TL), wide-ranging fishes over a broad spatial scale
K: Belt dimension used to survey highly mobile species (e,g, Kyphosidae, Scaridae, Siganidae, Lethrinidae, Serranidae, etc.)
L: Belt dimension used to survey demersal species (e.g., Chaetidontidae, Pomacantidae, Acanthuridae, Balistidae, etc.)
M: Belt dimension used to survey Pomacentridae including only herbivorous and excluding planktivorous species

single most dominant species and still persists as the most abundant (Green, 1996, 2002; Green et al., 2005; Whaylen and Fenner, 2006; Sabater and Tofaeono, 2006, 2007; Fenner and Carroll, in review). The overall community structure of reef fishes also does not seem to have changed drastically in the past three decades. In the late 1970s the family Pomacentridae dominated in terms of abundance while Scaridae dominated in terms of biomass, followed by Acanthuridae. Data from the latest surveys by PIFSC-CRED showed that Pomacentridae persists as the most numerically abundant family while Acanthuridae now dominates biomass, followed by Scaridae. This shift in biomass dominance from Scaridae to Acanthuridae could be attributed to the introduction of SCUBA spearfishing which targeted parrotfish, especially at night while they were sleeping. SCUBA spearfishing lasted from 1994 to 2000 and increased fishing efficiency 15 fold resulting in the removal of approximately 18.7% of the standing stock of parrotfish (estimated at 189 mt over this period; Page, 1998). Despite this increased fishing efficiency, the harvest did not exceed the maximum sustainable yield for all parrotfish species combined in Tutuila, which was calculated at 53.9 mt/ year (Page, 1998). Nevertheless, in 2001 DMWR banned SCUBA spearfishing, and the population of parrotfish has shown signs of recovery since then (Green, 2002; Green et al., 2005).

### *Variation in Abundance over Time*

Wass conducted the first quantitative assessment of fish populations in American Samoa between the years of 1977 and 1979 (Wass, 1982, unpub. manuscript). This was followed by a series of surveys conducted by Birkeland et al. (2003) in the 1980s to document the impact of COTS infestation on the reefs of American Samoa. It was not until the late 1990s and the early 2000s that more regular surveys have been conducted. During the period from the late 1970s to the mid 2000s it appears that fish populations on Tutuila have remained relatively stable in terms of mean fish density, with a slight increase occurring after an initial decrease between 1985 and 1988 (Figure 10.35). These results indicate that the reef fish populations of American Samoa are somewhat resilient as a number of disturbances have occurred throughout this time, including a major COTS outbreak in the early 1980s, hurricanes in the early 1990s and 2000s, subsequent declines in overall coral cover from 60% to 30%, and the occurrence of SCUBA spearfishing from 1994-2000. The data point from the year 2002 is considered an outlier due to the fact that surveys occurred during large recruitment pulses of *Ctenochaetus striatus*, which greatly biased the fish density values recorded that year.

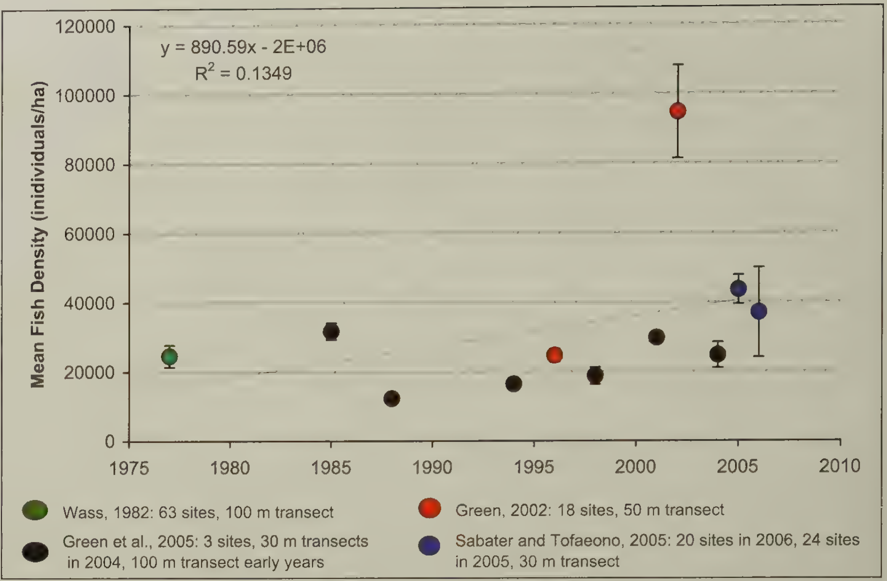


*Figure 10.35. Fishery-independent surveys conducted in American Samoa from 1977 to 2007. Data sources are listed in the graph.*

### *Historic Utilization of Fish Resources and Correlation with Present Day Preferences and Fish Community Structure*

In 1987 and 1989 an archaeological dig of faunal remains from a midden site at Toaga on the island of Ofu was conducted and is considered to be the largest fish bone assemblage from Western Polynesia (Nagaoka, 1992). This research shows what types of fish were being utilized by Samoans up to at least 3,000 years ago. The faunal remains were dominated by fish, followed by land vertebrates and shellfish. The 1987 dig showed that fish in the family Holocentridae had the most remains followed by Acanthuridae, Serranidae and Scaridae. Among the bones identified from the 1989 dig, Acanthuridae dominated the specimens recovered (with Diodontidae removed due to sampling bias) followed by Serranidae, Scaridae and Holocentridae (Figure 10.36). A number of factors affected the results, which includes sampling protocol, ecology, fishing techniques, social inputs and food preference. A correlation of present fish abundance (from underwater surveys done by Green 1996 and 2002) in Ofu with the number of identified specimen of the faunal remains for the major families showed a positive relationship (1987: r=0.580; 1989: r=0.619). This indicates present day assemblage may be similar to what was available in the fishery up to 3,000 years ago. A recent survey of Samoans indicated a strong preference for fishes in the family Acanthuridae over other fish groups (Kilarski et al., 2006), and the archaeological record suggests that this preference has persisted since prehistoric times. In contrast, the faunal composition of fish remains found in middens on the neighboring islands of Fiji and Tonga contained more parrotfish (Figure 10.36).

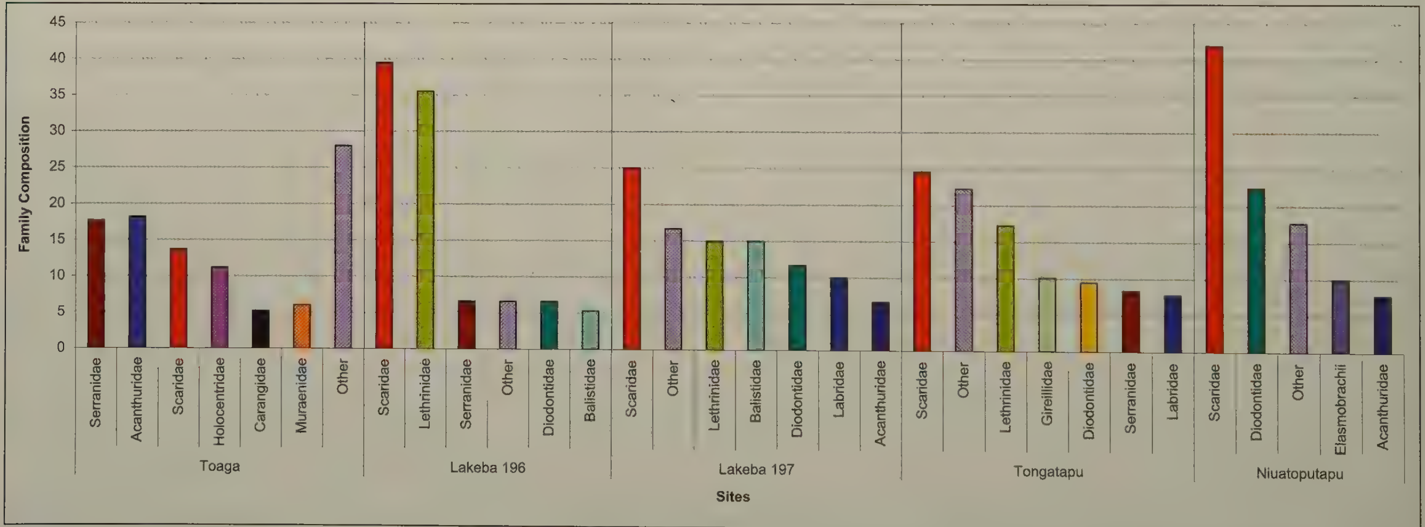


*Figure 10.36. Family composition of identified fish bone specimens from midden sites in the South Pacific. Toaga is located on Ofu in American Samoa; the other sites are located in neighboring Pacific island nations. Source: Nagaoka, 1992.*

### *Spatial Patterns In Biomass and Abundance of Fish Populations*

Determining spatial patterns in biomass and abundance assists managers in prioritizing certain areas for specific management purposes. While the coral reefs of American Samoa represent a relatively small system, research results have shown that issues of scale still exert an important influence on the distribution, abundance and biomass of reef fishes, including those targeted for subsistence and recreational purposes. In American Samoa, variations in biomass and abundance occur at a habitat scale (covering thousands of meters) with less variation occurring at a site and transect level (Sabater and Tofaeono, 2007).

### Island Comparisons

Figures 10.37 and 10.38 show the density and biomass adult reef fishes from different sites at the Manua Islands as well as Tutuila in 1996 and 2002. The island group of Manua, consisting of the three small islands of Ofu, Olosega and Tau, had a slightly higher biomass and density of adult fishes compared to the main island of Tutuila in both survey years (Green, 2002), although the differences do not appear to be significant. The data also show an increase in overall fish biomass and abundance both in Tutuila and in the Manua island group between 1996 and 2002. It should be noted that for this comparison, only adult fish were considered, thus avoiding the potential bias related to the large recruitment event that occurred in 2002. The data also indicate considerable variation in biomass and density among sites in the Manua islands and Tutuila during both survey years. (See also the PIFSC-CRED write-up at the end of this section which includes a comparison of Rose Atoll and Swains Island).

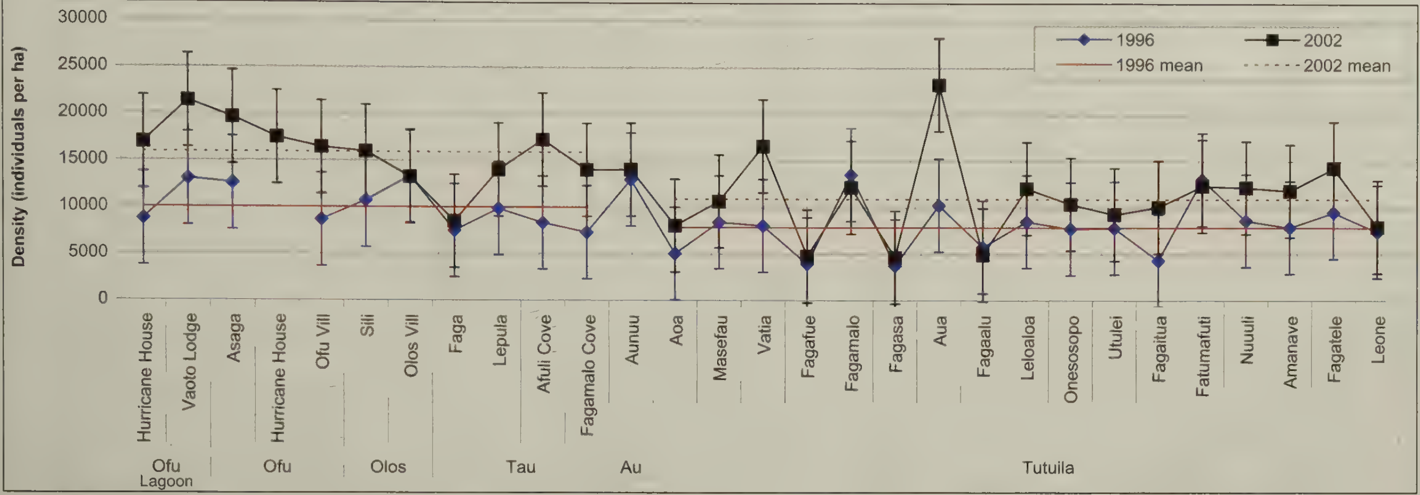


Figure 10.37. Density (ind/ ha) of adult reef fishes in Manua and Tutuila, American Samoa in 1996 and 2002. Means were calculated separately for Tutuila and the Manua Islands. Source: Green, 2002.

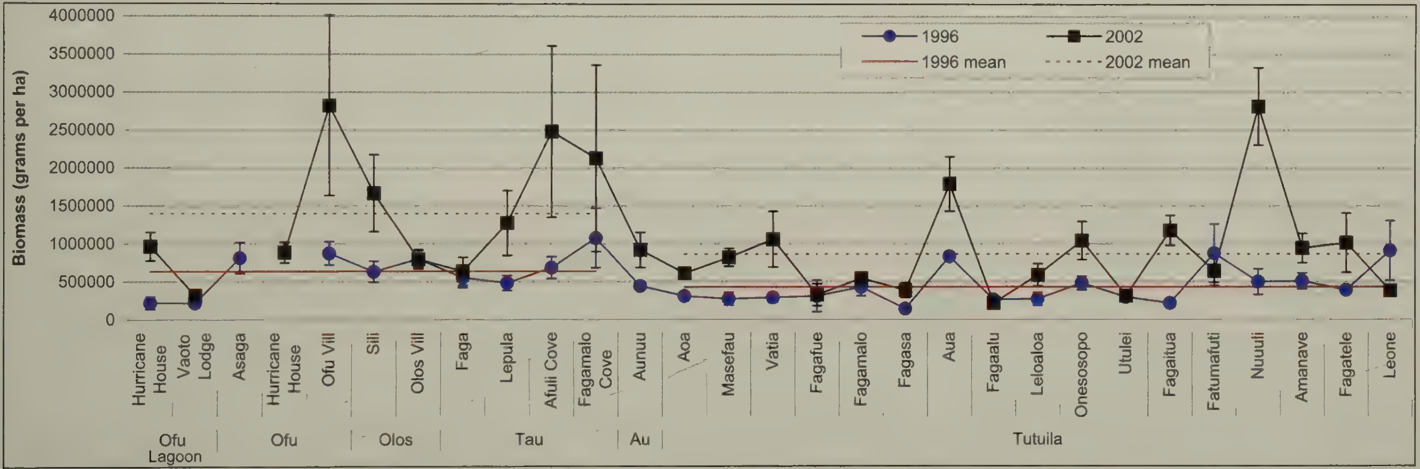


Figure 10.38. Biomass (g/ha) of adult reef fishes in Manua and Tutuila Islands, American Samoa in 1996 and 2002. Means were calculated separately for Tutuila and the Manua Islands. Source: Green, 2002.

### North-South and Habitat Variations

Biomass and species distribution differ between the north and south sides of Tutuila (Figure 10.39; Sabater and Tofaeono, 2006). Generally, the northern side of the island appears to have lower fish biomass than the southern side. This may be attributed to differences in the spatial extent of coral reef habitat and degree of exposure. The higher fish biomass recorded by Green (2002) and Sabater and Tofaeono (2007) on the south side of Tutuila may be related to the presence of a more extensive and well developed reef with higher bottom complexity (NOAA, 2005). The north shore, conversely, has a narrow fringing reef, which provides less habitat and shelter for fish and thus supports lower biomass and abundance.

The results of Wass' 1970s surveys show variations occur in species composition, biomass and fish density between reef flats and fore reefs, as well between fringing reefs and bank reefs. Recent research shows that despite the basalt nature of the benthos, exposed point areas generally have a higher biomass and abundance of reef fishes than embayment areas where more "true" coral reef structure occurs (Figure 10.39; Sabater and Tofaeono, 2007). It should be noted, however, that much variation occurs when comparing data from points and embayments in different sectors of Tutuila and no clear pattern is apparent and may be a result of smaller-scale, within-habitat variations. For example, the higher fish abundance and biomass values recorded at some exposed points may result from the presence of large schools of *Planktivorous fusiliers*. Similarly, some bay areas have higher abundance and biomass of fish due possibly to greater habitat complexity and the presence of patch reef habitats.

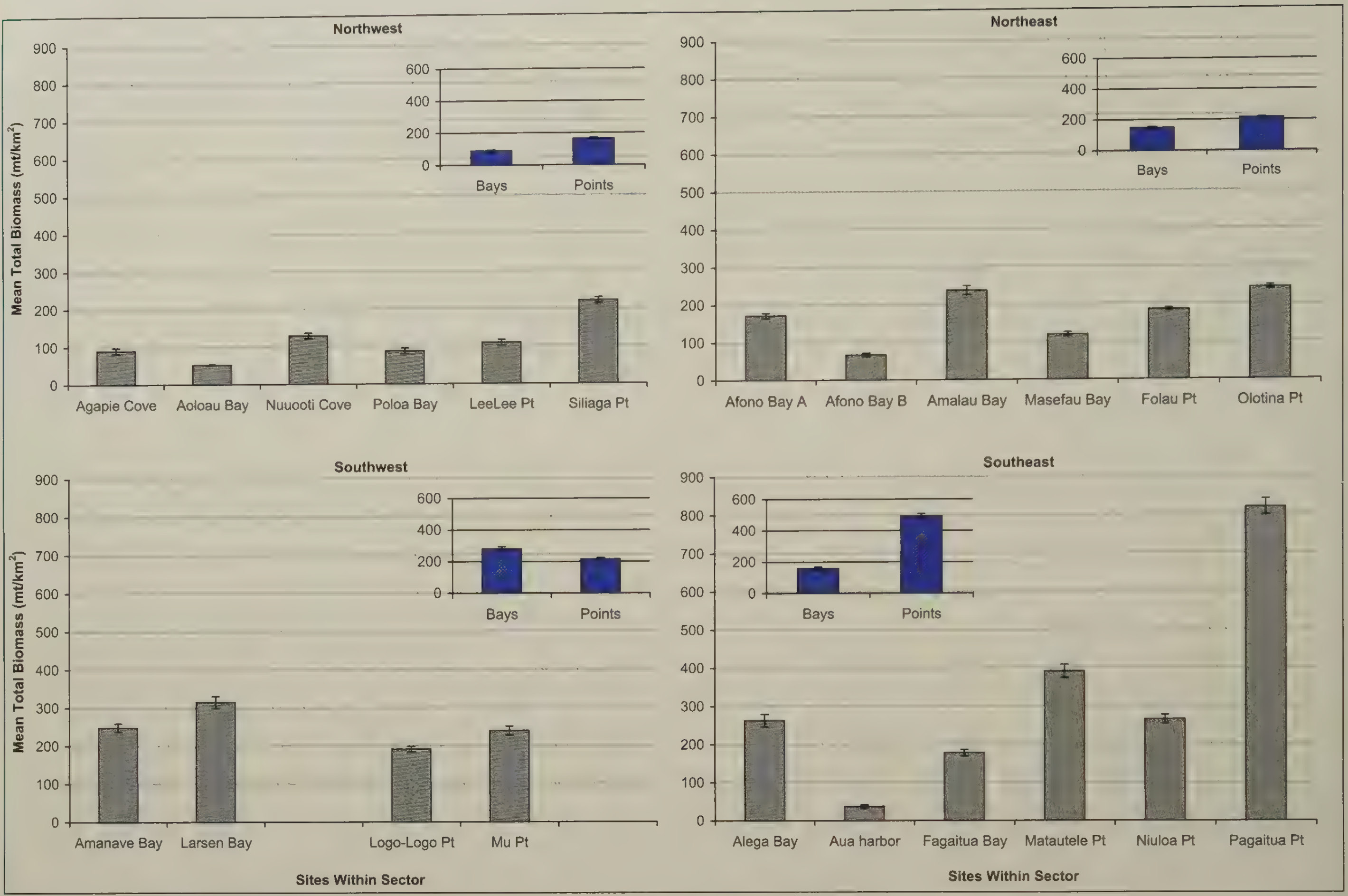


*Figure 10.39. Biomass distribution of key reef species around Tutuila showing variation between exposed points and sheltered bays. Source: Sabater and Tofaeono, 2007.*

## PIFSC-CRED Fishery-Independent Fish Monitoring

Quantitative assessment and monitoring of shallow reef fish assemblages was conducted throughout American Samoa in 2002, 2004, 2006 and 2008 by PIFSC-CRED; data from 2008 is not analyzed here but will be presented in future editions of the report. Subsequent biennial monitoring surveys are planned to document temporal variability in reef fish assemblages. Reef fish communities were found to be comprised mainly of herbivores (> 50% total biomass), followed by carnivores and lesser apex predators. The exception was Swains Island, where apex predators such as barracuda and jacks accounted for approximately 60% of fish biomass (Brainard et al., in review).

### *Methods*

In 2006, quantitative belt transects (all fish sizes), stationary point counts (medium-sized fish 25-50 cm), towed-diver fish surveys (for large fishes > 50 cm) and random swims (for species presence) were conducted at previously visited locations and new sites, using the same PIFSC-CRED methodologies as in previous years (see 2005 edition of this report). To allow an island-wide comparison of fish from all size classes, belt transect data was combined and averaged for the three survey years to mitigate the higher variability in total fish biomass found at Rose Atoll and Swains Island, where extensive but patchy schools of large fish were observed. Data from lagoon sites at Rose Atoll were excluded as these sites often had a very high biomass of fish and a very limited area of coral reef habitat. Towed-diver survey data was combined and averaged for the three survey years to examine fish >50 cm, with lagoon sites at Rose Atoll again excluded since tows within the lagoon were largely over sandy, fish-poor habitat.

### *Island-Wide Comparison Of Fish From All Sizes Classes*

Total fish biomass (all species and size-classes pooled) was highest at Rose and Swains, intermediate at the Manua Islands, and lowest at Tutuila (Figure 10.40). Fish biomass in the smallest size classes (<20 cm total length or TL) was similar across all islands, but lower at Swains. Fish biomass in the 20-39 cm range was comparable across islands, except much higher at Rose. Large fish (>50 cm) biomass was overwhelmingly highest at Swains, predominantly due to schools of barracuda and jacks.

### Large Fish

Biomass density of large fish (>50 cm TL) from towed-diver surveys was three times greater at Swains and Rose than at Tutuila and the Manua Islands (Figure 10.41; PIFSC-CRED, unpub. data). In contrast, the Swains and Rose values were only a fraction of values from other U.S. Pacific remote islands (e.g., Jarvis, Wake; see PRIA chapter).

### Medium Fish

Biomass density of medium-large fish (>25 cm TL, from SPC surveys) was also nearly three times higher at Swains and Rose (~0.6 t/ha) than at Tutuila (~0.2 t/ha), while intermediate at the Manua Islands (PIFSC-CRED, unpub. data).

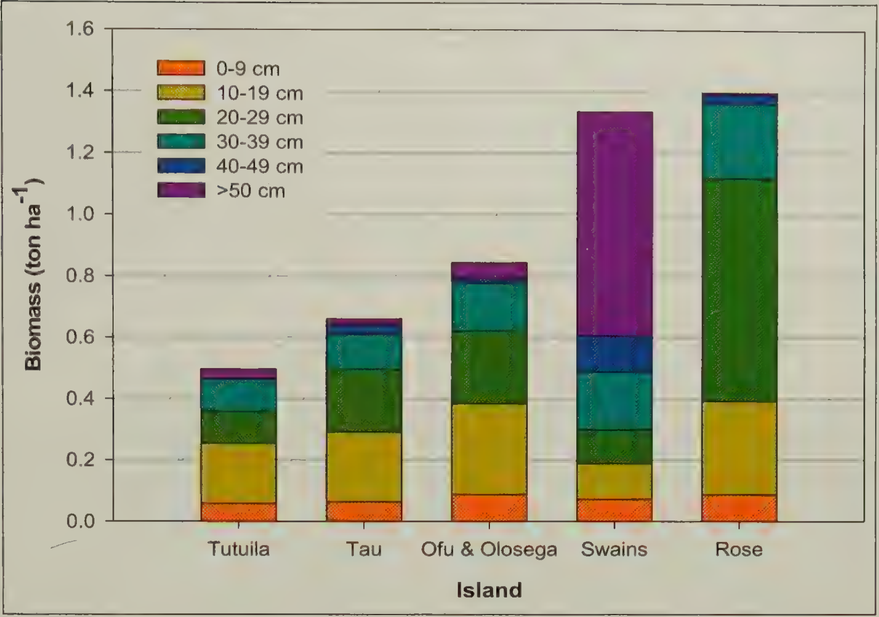


*Figure 10.40. Mean total fish biomass for all size classes across American Samoa as measured in belt transects conducted along the fore reef (2002 to 2006 data pooled). For each island, fish < 50 cm are divided into five 10-cm classes. Source: Brainard et al., in review.*

### *Tutuila Island*

From February 18-25, 2006, the fish census team surveyed 22 stations in the vicinity of Tutuila, including one at Taema Bank (south of Pago Pago Harbor), one at Aunuu, and 20 around Tutuila. Habitat types surveyed included reefs within bays and exposed outer reef slopes. All sites were resurveys of sites established by PIFSC-CRED in February of 2002 or 2004. The same quantitative methods (belt transect and SPC) were conducted at each of these sites. Towed-diver surveys were conducted along 44 tow tracks covering 90 ha of habitat.

As in previous years, medium-large fish biomass was lowest at Tutuila Island (0.19 t/ha; Figure 10.40) and was mostly composed of herbivores. Target families commonly observed were parrotfish (*Scarus* spp.), grouper (*Cephalopholis* spp.), and snapper (*Macolor* spp.). A few dog-tooth tuna (*Gymnosarda unicolor*) were seen along the north shore. Several humphead wrasses (*Cheilinus undulatus*) were seen at Tutuila, but no bumphead parrotfish (*Bolbometopon muricatum*) were recorded on SPCs.

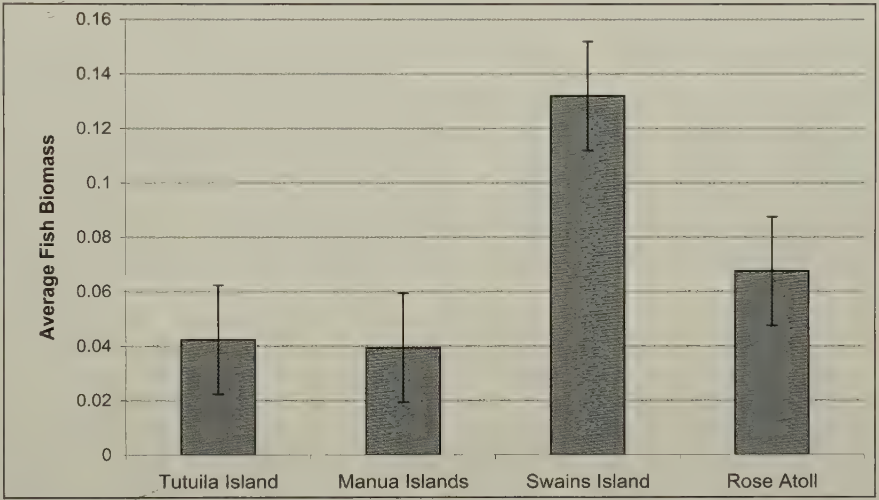


*Figure 10.41. Large (> 50 cm) fish biomass as observed in towed-diver surveys conducted throughout American Samoa. Source: Brainard et al., in review.*

Of the twelve species of grouper (Serranidae, Epinephelinae and Anthiinae) observed, most common were flagtail grouper (*Cephalopholis urodeta*), followed by peacock grouper (*C. argus*). The most common snappers, although not abundant, were smalltooth jobfish (*Aphareus furca*), onespot snapper (*Lutjanus monostigma*), and blacktail snapper (*L. fulvus*). In contrast to 2004, twinspot snapper (*L. bohar*) were rather rare and represented mostly by juveniles. The most frequently occurring parrotfish was the redtail parrotfish (*Scarus japanensis*). Bullethead parrotfish (*Chlorurus sordidus*) were seen less frequently but were typically more numerous. The most frequently occurring species of butterflyfish, as in 2004, was the reticulated butterflyfish (*Chaetodon reticulatus*). Twenty-nine species of damselfishes (Pomacentridae) were observed around Tutuila. Most common were the midget chromis (*Chromis acares*), the bicolor chromis (*C. margaritifer*), the half and half chromis (*C. iomelas*), the charcoal damsel (*Pomacentrus brachialis*), Dick's damsel (*Plectroglyphidodon dickii*) and the Johnston Island damsel (*P. johnstonianus*).

The most commonly observed large fish (> 50 cm TL) on towed-diver surveys was the bigeye jack (*Caranx sexfasciatus*) seen in two large schools and the blackfin barracuda (*Sphyraena qenie*) seen mostly in a single school. Parrotfish were the third most commonly observed large fish, with frequent sightings of the Pacific steephead parrotfish (*Chlorurus microrhinos*) and of the redlip parrotfish (*Scarus rubroviolaceus*). The most commonly observed shark for this survey period was the benthic feeding reef whitetip shark (*Triaenodon obesus*) with three observations, both the reef blacktip shark (*Carcharhinus melanopterus*) and the Galapagos shark (*C. galapagensis*) were observed once. Other notable observations included nine sightings of the Napoleon wrasse and one towed-diver sighting of the bumphead parrotfish.

### *Manua Islands (Ofu, Olosega and Tau)*

From February 26 to March 4, 2006, the fish REA team surveyed 12 stations around Ofu-Olosega and nine around Tau. A minimum of 171 coral reef fish species were recorded. Medium-large fish biomass was twice as high around Ofu-Olosega (0.44 ton ha-1) than at Tutuila. Most of the biomass in the Manua islands was composed of herbivorous fish.

Of all fishes around Ofu-Olosega, surgeonfish and wrasse were the most abundant and diverse groups. Sharks were very rare, with only one white-tip (*T. obesus*) and one black-tip (*C. melanopterus*) seen in 2006, representing a downward trend since 2002. No bumphead parrotfish (*B. muricatum*) were sighted, but a few humphead wrasses (*C. undulatus*) of various sizes were observed. Common targeted fish families were parrotfish, snappers and groupers. Parrotfish were diverse (12 species) and included large individuals (e.g., *C. microrhinos*). Common snappers were *L. bohar* and *Macolor* spp.

A heavy recruitment pulse was detected at one particular spot: a very dense aggregation of *Ctenochaetus striatus* in a major reef groove (OLO-5), being preyed upon by a number of jacks (mostly *Caranx melampygus*). Very few *C. striatus* juveniles were seen elsewhere around these two connected islands. Other species counted with relatively high juvenile numbers included *Gomphosus varius*, *Acanthurus nigroris* and, in low relief habitats, *Halichoeres margaritaceus*.

Medium-large fish biomass around Tau was slightly lower (0.39 ton ha-1; Figure 10.40) than around Ofu-Olosega. During the 2006 survey, no sharks were seen by the fish REA team at Tau. Common medium-size fish were parrotfish (e.g., *Scarus fosteni*, *S. oviceps*), the grouper *Cephalopholis argus*, goatfish (*Parupeneus cyclostomus* and *Mulloidichthys vanicolensis*), snappers (*Aphareus furca*, *Lutjanus kasmira*, *L. monostigma*, *L. gibbus*, surgeonfish (*Naso* spp., *Acanthurus nigricauda*), and triggerfish (*Odonus niger*). A large school of about 200 barracuda (*Sphyraena helleri*) was also recorded. Several humphead wrasses (*C. undulatus*, 50-120 cm TL) were seen, including seven at one site. One unique sighting was a deep, long crevasse in the reef at the top of a vertical drop-off (site TAU-2) where several large fish (*Plectorhinchus picus*, *Diodon hystrix*, *Macolor macularis*, *Sargocentron spiniferum*) were seeking shelter.

### *Swains Island*

From February 11-13, 2006, the fish census team surveyed eight stations at Swains; all were resurveys of sites previously established by PIFSC-CRED. In 2006 only about five people resided on the island. Potential local fishing targets included most species of larger fish; the level of fishing pressure from external sources is unknown.

The most numerically abundant species around the island was the midget chromis (*Chromis acares*), followed by purple queen (*Pseudanthias pascalus*). Small arc-eye hawkfish (*Paracirrhites arcatus*) were commonly recorded. As a group, wrasses were the next most common family with 27 species recorded. Few surgeonfish, grouper and snapper were observed, and parrotfish, goatfish and emperor fish were rare. A large school of rainbow runner (*Elagatis bipinnulata*) was recorded by SPC on the eastern side of the island. Medium-large fish recorded by SPC along the northern side were fairly abundant and diverse (e.g., *L. bohar, C. argus, Macolor niger* and *M. macularis*, *Naso* spp.). As in previous years, no bumphead parrotfish were observed at the island. Medium-large fish biomass at Swains Island was the highest in American Samoa at 0.6 ton ha-1, although this value is low compared to values recorded in the PRIA and northern CNMI (see PRIA and CNMI chapters).

On towed-diver surveys, rainbow runners (*Elagatis bipinnulata*) were the most commonly observed large fish species with 1,006 observations; most were observed swimming in a single school. Barracuda (*Sphyraena qenie*) were also seen in large schools, with 218 sightings. Other common large fish included blacktongue unicornfish (*Naso hexancanthus*) and twinspot snapper (*L. bohar*), each with 26 individuals observed. Few sharks or jacks were seen during towed-diver surveys, with the reef whitetip shark (*T. obesus*) being the most common shark with four records, and bluefin trevally (*C. melampygus*) the most common jack with five records. Nine humphead wrasses (*C. undulatus*) were sighted at Swains.

### *Rose Atoll*

From March 5-9, 2006, fish REAs recorded 158 species at 14 monitoring stations around Rose Atoll and in the lagoon.

Medium-large fish biomass around Rose was the second highest in the American Samoa and was similar to 2002 (0.55 ton ha-1). Sharks (white-tip and black tip) were common, mainly in very shallow water just below the surf zone. The lagoon patch reef on the west side harbored a high density and diversity of fishes, including large ones (e.g., large schools of *Scarus frontalis*, *L. kasmiri*, *M. vanicolensis*). The outer slope was also characterized by healthy fish communities and good visibility (>30.5-61 m). Parrotfish and surgeonfish were abundant along the southwest side, especially at the site of the 1993 longline vessel grounding (ROS-7). Dense schools of orangespine unicornfish (*Naso lituratus*) and convict tang (*Acanthurus triostegus*) were common here as well. Heavy cover by turf algae and cyanobacteria in response to iron-enrichment from corroding wreckage was still visible at this outer reef slope station, and a few pieces of wreckage were spotted in the area. No major recruitment pulses were observed but small juveniles of bird-wrassse (*Gomphosus various*) and arc-eye hawkfish (*P. arcatus*) were common.

The most commonly observed large fish (>50 cm TL) on towed-diver surveys was the blackfin barracuda (*S. qenie*) with 399 observations, 296 of which were in large schools. The second most commonly observed fish was the big-eye trevally (*C. sexfasciatus*) with 220 observations, with the majority observed in one large school outside the north pass of the atoll. Observations of both parrotfish and snappers were also notable with 197 and 192 individuals observed respectively. The Pacific steephead (*Chlorurus microrhinus*) and the twinspot snapper (*L. bohar*) accounted for the majority of these observations. The most commonly observed shark for this survey period was the benthic feeding reef whitetip shark (*T. obesus*) with 23 observations, compared to only eight the previous survey period. Other sharks observed in few numbers included the blacktip reef shark (*C. melanopterus*), the gray reef shark (*C. amblyrhyncos*) and lemon shark (*Negaprion acutidens*). Thirteen humphead wrasse were recorded, but no bumphead parrotfish were seen, consistent with previous years.

## Status of the Coral Reef Fishery

### Fishery-Dependent Monitoring and Surveys

Although some reports suggest coral reef fish stocks in American Samoa are overfished, a recent comparison of data from fishery-independent monitoring and fishery-dependent surveys provides new insight into how fishing affects coral reef fish populations. Data was obtained from the various fishery-dependent studies and monitoring that has been conducted by a number of researchers working at DMWR over the past 30 years (Table 10.8). These studies document catch and effort from commercial and subsistence fisheries beginning in 1977 and 1985 respectively, and this data was combined with data collected from fishery-independent studies (see 'Status of Coral Reef Fish Populations' earlier in the chapter). Fishery-dependent data from the Inshore Fishery Documentation Program under DMWR was compiled and made available to the public through the Western Pacific Fisheries Information Network database (http://www.pifsc.noaa.gov/wpacfin). The information in this section includes time series data that examines various parameters that affect the status of coral reef fish communities in American Samoa.

*Table 10.8. Fishery-dependent surveys conducted in Tutuila, American Samoa from 1980 to 2006.*

| STUDY | PROJECT | YEAR | AVAILABLE DATA | METHOD USED | # OF SITES | TRANSECT OR SURVEY DIMENSION |
|---|---|---|---|---|---|---|
| Wass (1980) | Shoreline fishery documentation | 1977-1979 | Catch, effort, CPUE, catch composition | Roving catch and effort surveys | 9 | 18.8 x 3 km |
| Ponwith (1991) | Shoreline fishery documentation | 1990 | Catch, effort, CPUE, catch composition | Roving catch and effort surveys | 10 | 18.8 x 3 km |
| McConnaughey (1993) | Shoreline fishery documentation | 1992 | Catch, effort, CPUE, catch composition | Roving catch and effort surveys | 8 | 16 km |
| Saucerman (1995) | Shoreline fishery documentation | 1991-1994 | Catch, effort, CPUE, catch composition | Roving catch and effort surveys | 8 | 17 km |
| Page (1998) | Ecology, biology and fishery of parrotfishes | 1996-1998 | Stock, CPUE, catch, effort, age and growth parrotfishes | Market surveys | 3 | n/a |
| Coutures (2003b) | Shoreline fishery documentation | 2002 | Catch, effort, CPUE, catch composition | Roving catch and effort surveys | 36 | 42.8 km |
| Zeller et al (2006) | Coral reef fishery reconstruction | 1950-2000 | Catch and population data | Data re-construction and modeling | Territory wide | n/a |
| Brookins (2006) | American Samoa Fishery Documentation (WPFRMC) | 1982-2006 | Catch and effort data | Boat based and roving creel survey | Island wide | n/a |

### The Commercial Fishery

Commercial landings over the past 24 years have varied greatly. In the early 1980s catch dropped from a relatively high level to a moderate level before declining to a low level in the early 1990s (Figure 10.42). Catch increased in the mid 1990s, again reaching very high levels between 1997 and 1999 before declining sharply from 1999 to 2001 and remaining low since then.

It is thought that the sharp drop in commercial catch in the early 1990s was related to the impacts of two large hurricanes; Hurricane Ofa in 1990, and Hurricane Val in 1991. These two hurricanes caused the most significant damage of any hurricanes in the past 30 years. Damage from Hurricane Ofa was considerable due to its size, strength and the fact that it was a slow moving system; damage from Hurricane Val was largely a result of the storm's significant strength and the fact that the center of the storm directly hit Tutuila. Both hurricanes caused massive structural damage to buildings and homes as well as considerable environmental damage above and below the water. Most significantly for the fishery, the storms destroyed many fishing boats and resulted in the groundings of nine large ships.

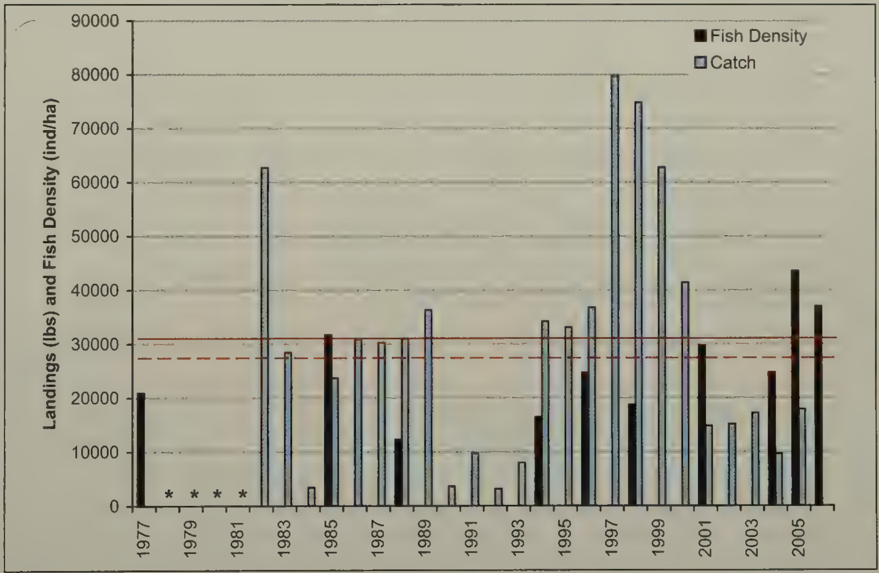


*Figure 10.42. Trend in commercial catch landings and fish density in Tutuila from 1982 to 2005. Mean landings is represented by the red dashed line; mean fish density is indicated by a solid red line. Asterisks (*) indicate years for which no data was collected. Sources: Wass, 1982; Green, 2002; Green et al., 2005; Sabater and Tofaeono, 2006; WPRFMC, 2007.*

Increased catches between 1994 and 1997, and especially between 1997 and 1999, were due mainly to the introduction of SCUBA spearfishing. Spearfishers predominantly targeted parrotfish at night. This method resulted in a 15 fold increase in catch, and by 1997, accounted for 89% of the total catch in the parrotfish fishery (Page, 1998). The total commercial catch then started to decline, presumably because the increased efficiency of SCUBA spearfishing increased exploitation rates of some parrotfish species close to or beyond their maximum sustainable yield (Page, 1998). In 2001, SCUBA spearfishing was banned, decreasing overall catches to low levels where they have remained since.

When examining commercial fishing effort over the past 30 years, either based on expanded fisher hours or the number of trips made per year (Figure 10.43), the same general trend exists as described above. This shows that catch levels in American Samoa over the past 30 years have been determined strongly and primarily by the amount of fishing effort. As such, there was a strong positive correlation between commercial landings and effort for number of boat trips per year (r=0.849), and for total annual fisher hours (r=0.406).

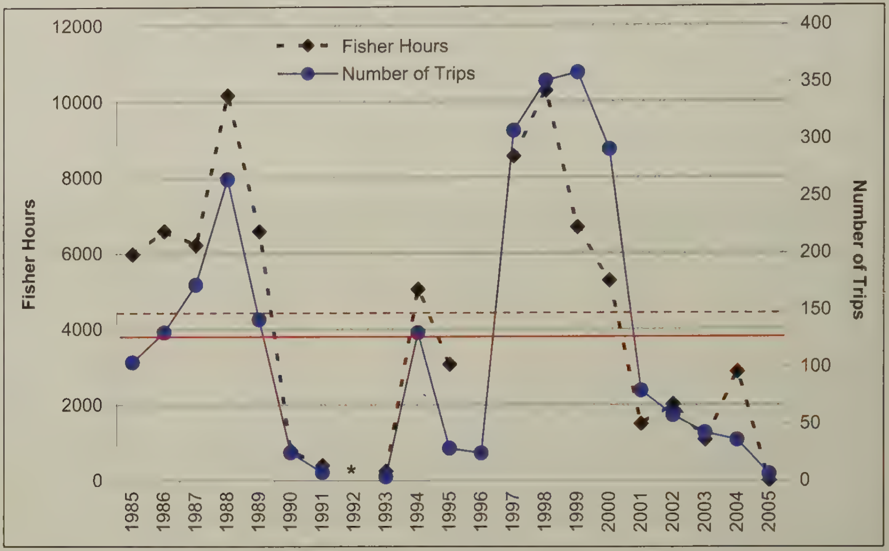


*Figure 10.43. Trend in commercial fishing effort, expanded number of fisher hours and expanded number of trips in Tutuila, 1985 to 2005. Mean fisher hours is represented by a red dashed line; mean number of trips is indicated by a solid red line. Source: WPRFMC, 2007.*

Throughout the same period, fish density has remained relatively constant (Figure 10.44). Since fish density has remained relatively stable through time, the observed decline in catch is not attributable to a limited or declining resource (fish density correlated negatively with catch, r=-0.407), but instead appears to result from a decline in effort. It is also worth noting that fish populations have remained stable throughout the last thirty years despite the numerous disturbances that occurred between the late 1970s and the present as mentioned previously. This suggests that reef fish populations in Tutuila are considerably robust and resilient despite notable declines in coral communities.

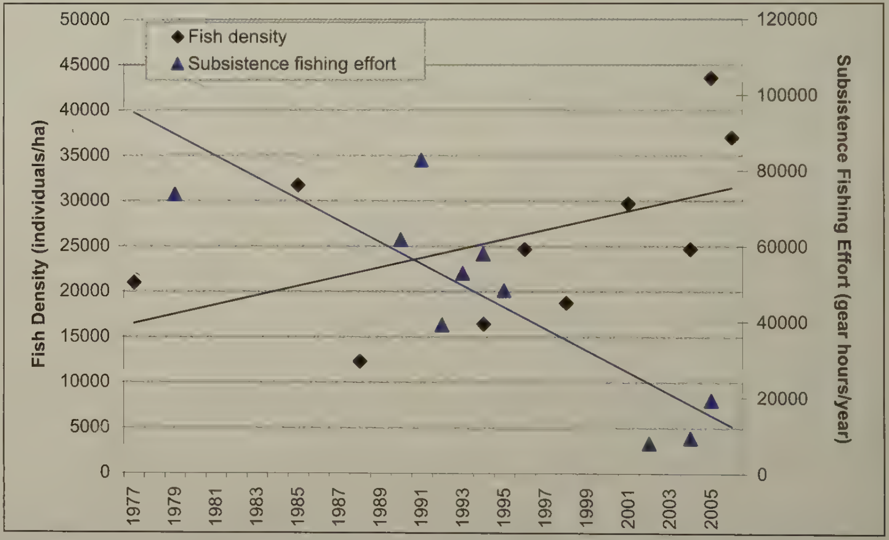


*Figure 10.44. Trend in subsistence fishing effort (total gear hours/year) and fish density (individual/ha) in Tutuila from 1977 to 2005. Sources: Wass, 1982; Green, 2002; Green et al., 2005; Sabater and Tofaeono, 2006; WPRFMC, 2007.*

### *The Subsistence Fishery*

Subsistence fishing effort has also declined markedly in the past 30 years (Figures 10.44 and 10.45). Effort dropped from relatively high levels in the late 1970s and early 1990s (60,000-80,000 gear hours/year), to moderate levels in the early to mid 1990s (40,000-60,000 gear hours/year). A further drop occurred in the early 2000s, when effort levels were low (4,000-8,000 gear hours/year; http://www.pifsc.noaa.gov/wpacfin).

This decrease in fishing effort is attributed to a general shift from subsistence fishing to a cash-based economy. Despite the territory's Polynesian heritage and the associated traditional and cultural importance of fishing, modernization has shifted the society toward a cash-based economy where the majority of the population relies on paid employment. This in turn has enabled American Samoans to purchase food instead of fishing for their protein source. Such dietary changes and economic modernization has been documented throughout Pacific Island populations in the second half of the 20th century and is thought to be responsible for the increase in numbers of people that are overweight or obese (Ulijaszek, 2002; WHO, 2003). Kilarski et al. (2006) reported that American Samoans still consider fishing an important part of their culture and engage in fishing occasionally. However, the majority of the population does not engage in subsistence or commercial fishing activities but fishes in more of a recreational manner.

Data from the U.S. Census Bureau (1990, 2000) shows an increase in the labor force in the past 10 years with 52% of the population now employed and only 7% involved in subsistence activities. Thirty-five percent (35%) of the workforce was involved in manufacturing (including cannery work), 17% in education, health and social service, and 9% in public administration. Only 3% worked in agriculture, forestry, fishing, hunting and mining combined. There was a steady increase in employment in government and private sectors from 2000 to 2004, while employment at the canneries decreased every year starting in 2001. These social dynamics have led to a decrease in fishing effort in the past three decades as reported by Ponwith (1991), McConnaughey (1993), Saucerman (1995) and Coutures (2003a).

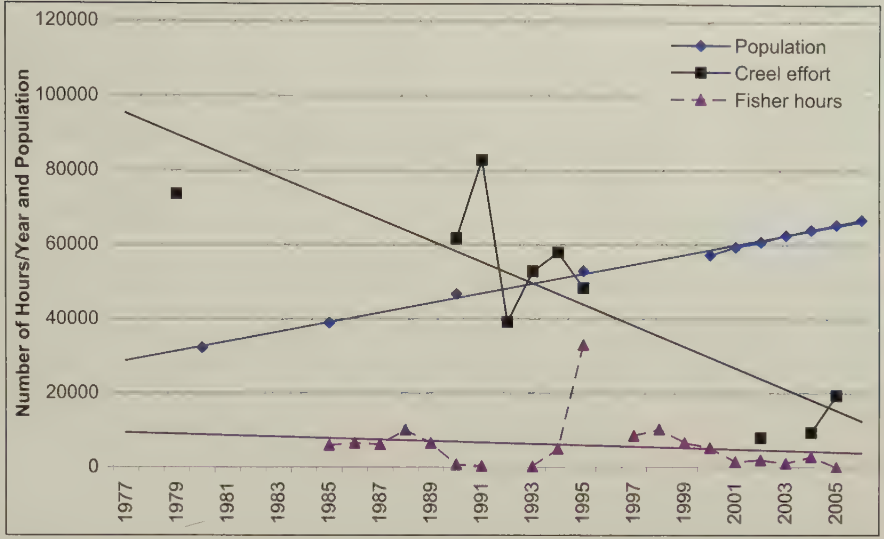


*Figure 10.45. Trends in subsistence and commercial fishing effort (number of hours/year) and population size in Tutuila from 1979 to 2005. Linear trend lines shown for each data set. Consecutive year data points are indicated by a line. Sources: U.S. Census Bureau, 1990 and 2000; WPFMC, 2007.*

### *Human Population and Fishing Effort*

It is commonly assumed that increases in human population levels lead to over-exploitation of coral reef resources, including fish stocks. The situation in American Samoa is, however, quite different. Although the human population has continued to increase over the past 30 years, commercial and subsistence fishing effort has declined, relatively and absolutely. Subsistence fishing effort (gear hours/year) has declined over the past three decades, with a strong negative correlation between population and subsistence effort (r=-0.926; Figure 10.45). Although commercial fishing effort has varied throughout this period, there seems to have been a decline in effort from 1995 onwards, with the exception of a spike in the mid 1990s prior to the ban on SCUBA spearfishing. There was also a slight negative correlation between population increase and commercial fishing effort (r=-0.255 for fisher hours; r=-0.142 for boat trips). This analysis demonstrates that an increase in population does not necessarily result in increased fishing pressure, and suggests that fishing pressure is better represented by measures of effort and catch than by human population levels.

Over the past 30 years, commercial landings of reef fish have varied considerably due predominantly to the effects of two factors: 1) two large hurricanes in the early 1990s which caused a decrease in fishing effort; and 2) SCUBA spear fishing between 1994-2000, which increased effort and efficiency and therefore catch. Despite the differences in catch and effort caused by these two factors, catch of reef fish has still declined overall and is currently at a low level. Subsistence fishing effort has also declined sharply over the past thirty years to a low level. These declines in effort, and therefore catch, are attributed to a shift in the resident population's focus away from subsistence activities and toward a cash-based economy and is apparent despite a large increase in the human population. At the same time, density of reef fish populations has remained relatively constant, and community composition has varied little. It therefore appears that reef fish populations in American Samoa are in relatively good health and are likely to stay the same or improve if current trends continue.

There is still some concern regarding overall fish biomass levels as well as biomass of large and medium-sized fish in American Samoa, since PIFSC-CRED data indicate that values are significantly lower than at neighboring island groups. A lack of baseline information regarding fish populations makes it difficult to assess the current status of reef fish populations and complicates comparisons between islands within and among regions, especially given the unique and individual characteristics of the islands themselves. Overall fish biomass, as well as community composition of reef fish, may differ due to natural factors (e.g., type of island, extent of reef development, availability of food, extent of suitable juvenile and adult habitat, diversity of available habitat types, rugosity, wave action, larval supply and connectivity) as well as anthropogenic factors (e.g., fishing pressure, pollution, eutrophication and sedimentation, level of management protection, human population etc.). Previous studies (e.g., CRAMP, 2007; Nguyen and Phan, 2007; Brokovich et al., 2005; Lara and Gonzalez, 1998) have found that the structure of coral reef fish communities involves complex interactions of a number of factors, and that each factor alone explains only a small portion of the variability. A combination of factors, however, can be used to explain a significant portion of the variability.

Fishing pressure over the years has undoubtedly affected reef fish populations around the islands of American Samoa. It is unclear, however, to what extent fishing has altered reef fish populations, and to what extent fishing has altered reef fish populations at each island. It is also unclear the extent to which the other factors mentioned above have influenced current patterns in reef fish populations within and between these islands. Habitat parameters, for example, have been found to have significant importance in structuring coral reef fish communities (Brokovich et al., 2006) and this is also likely the case in American Samoa, which has high, eroding, volcanic islands as well as coral atolls. Swains Island is geographically part of the Tokelau Island group and is therefore likely to have more in common with other islands of this group than with the islands of American Samoa. The reefs of American Samoa, particularly around the main island of Tutuila, have limited areas of shallow water habitat (e.g., reef flats, back reef pools, lagoons, seagrass beds and mangroves), and significant portions of these habitats have been altered or destroyed in Tutuila through development. The limited availability of suitable juvenile habitat is likely to limit the abundance of certain species of reef fish that rely upon such habitat during their recruitment and juvenile life-history stages, ultimately affecting the number of adults that are found on the reefs. Declines in coral cover over the past 30 years and associated decreases in topographic complexity may also have had profound effects on the reef fish community. So, while previous and current fishing pressure is of obvious importance, other factors have to be taken into account when examining the current structure of coral reef fish communities and populations within and between the islands of American Samoa. Multivariate analyses are currently being conducted for reef fish populations in American Samoa to determine the influence of a number of the variables mentioned above.

## INVERTEBRATES

Shallow water invertebrates of American Samoa have been catalogued in a recent field guidebook (Madrigal, 1999). Initial studies indicate high invertebrate species diversity (Table 10.1). Green (2002) reported low but stable populations of giant clams on Tutuila and Ofu-Olosega and higher populations on Tau, which increased from 1996 to 2002. Green and Craig (1999) reported much higher populations of giant clams in Rose Atoll lagoon than elsewhere in American Samoa. Green (2002) also reported low numbers of COTS at all sites, including on Ofu where persistent populations were reported by others (Fisk and Birkeland, 2002). Brown (pers. comm.) observed a large and diverse community of sponges in some deep areas of Pago Pago harbor, including some very large barrel sponges and a community of sea fans in the harbor.

Courtures (2003) reported a study of the lobster populations of Tutuila. Since most lobsters hide during the day and come out at night to forage, surveys were conducted at night, in shallow water just seaward of the reef crest. The main commercial species in American Samoa is the spiny lobster (*Panulirus penicillatus*), which lives at 1-5 m depth in areas of high surge and surf. The slipper lobster *(Parribacus caledonicus)* is common and lives at depths less than 10 m. *P. antarcticus* is relatively rare and forages on the crest and outer reef flat. *P. versicolor* is very rare, and can be seen by day. Research catches averaged 1.1 kg/hr for spiny lobster and 1.4 kg/hr for slipper lobster, but catch rates varied between individual researchers. The study results produced a total population estimate for spiny lobsters at only 9,300 around Tutuila, in part because their preferred habitat is a narrow band only about 20-25 m wide seaward of the reef crest.

### *Territorial Monitoring Program*

#### *Methods*

Abundances of non-cryptic diurnal macro invertebrates were recorded by species along the four 1 x 50 m transects (8-10 m depth) surveyed at each of the 11 TMP monitoring sites on the reef slopes of Tutuila. Branching corals were not searched for cryptic commensal species, and cryptic habitats such as reef holes were not searched.

#### *Results and Discussion*

Very few invertebrates were recorded during TMP surveys. Only three: a small burrowing urchin (*Echinostrephus molaris*), a small massive orange sponge, (*Styllisa massa* or *S. flabelliformis*), and a thin grey encrusting sponge (*Dysidea* sp.) were common in patchy distributions. In 2006, the urchin was most common, followed by the orange sponge and the encrusting sponge (Figure 10.46). Researchers observed no COTS (*Acanthaster planci*), tritons (*Charonia tritonis*), or lobster (*Palinurus* and *Scyllarus* spp.). Although all are known from American Samoa, the first two species are considered rare and lobsters primarily inhabit shallow water and are rarely seen during the day. Giant clams, which are heavily fished on populated islands, were uncommon in belt transects, with a density of 0.37/100 m². Sea cucumbers were more abundant in sandy areas of lagoons. A survey of the reef crest at Nuuuli found a narrow band with populations of the urchin *Echinothrix calimaris* as high as 160/100 m². An encrusting green or blue ascidian (*Diplosoma simile*) was common within transects in Fagatele Bay in 2007 and accounted for 4% of total cover. Because many invertebrates are nocturnal or have specialized habitat requirements, these results should not be taken as indicative of total populations.

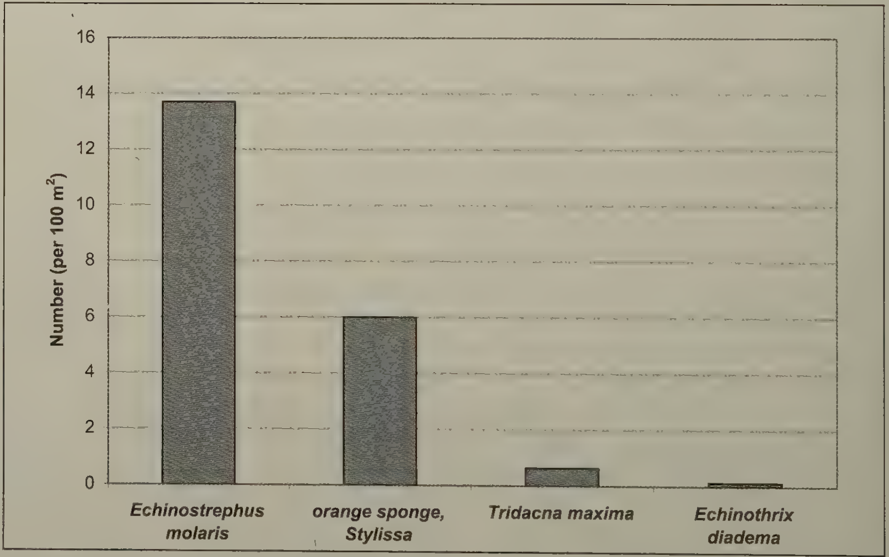


*Figure 10.46. Diurnal invertebrate densities on Tutuila reef slopes (9 m depth) in TMP transects in 2006. Source: Fenner and Carroll, in review.*

## PIFSC-CRED Rapid Assessment and Monitoring Program

### *Methods*

PIFSC-CRED utilized belt transects and quadrats to assess the populations of marine invertebrates throughout American Samoa in 2002, 2004 and 2006 (Brainard et al., 2007). Branching corals were searched for invertebrate commensal crabs as part of this study.

### *Results and Discussion*

Brainard et al. (in review) found the diurnal invertebrate community of the high islands of Tutuila, Ofu-Olosega and Tau to be dominated by echinoids, while Swains and Rose Atoll had more trapezid crabs and hermit crabs (Figure 10.47) which were mostly found among branches of corals, particularly *Pocillopora*. PIFSC-CRED data also confirmed the report of high numbers of giant clams in the Rose Atoll lagoon, and found that Tau had more giant clams than the other islands, particularly on its north and west sides, though Tutuila had good numbers at a few sites. Swains had more COTS than the other islands, though population densities were not high.

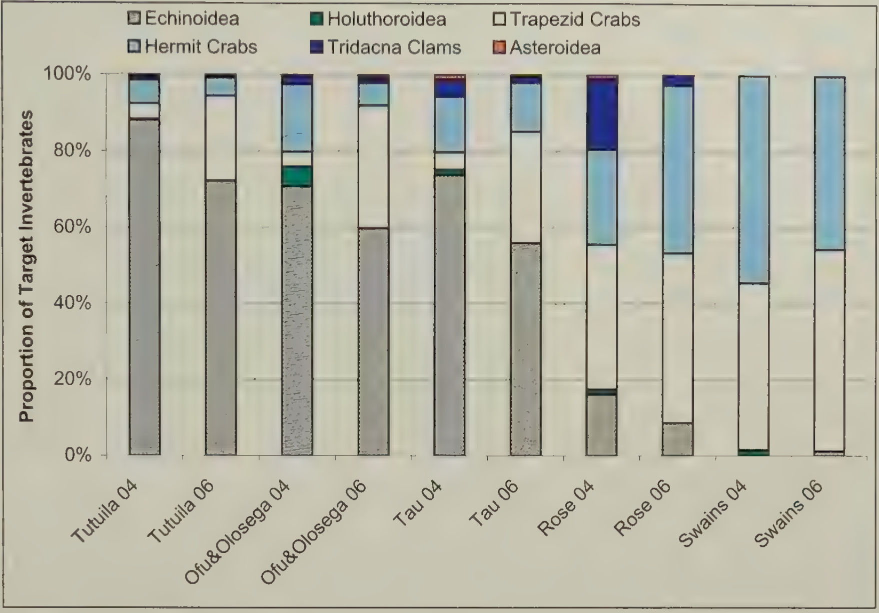


*Figure 10.47. Target invertebrates by island in 2004 and 2006. Source: Brainard et al., in review.*

## MARINE MAMMALS

Thirty three species of marine mammals are known to occur in the tropical South Pacific, and eleven of them have been observed in the waters of American Samoa (Dolar, 2005), including humpback whale, minke whale, sperm whale, killer whale, short finned pilot whale, common bottlenose dolphin, spinner dolphin, pantropical spotted dolphin, rough toothed dolphin, Cuvier's beaked whale and false killer whale (Utzurrum et al., 2006). Sperm whales and humpback whales are listed as endangered under the U.S. Endangered Species Act (Utzurrum et al., 2006). Research on humpback whales (*Megaptera novaeangliae*) in the territory has been conducted by Robbins and Matilla from 2003 to 2006. Territorial waters of American Samoa have been identified as a wintering area for humpbacks, which arrive in June and remain through December; peak numbers are usually seen during September and October (Dolar, 2005).

Most marine mammal research in the South Pacific is devoted to large whales. Information about small whales and dolphins comes from opportunistic efforts of individual researchers (Dolar, 2005). At present, information on the distribution and ecology of small cetaceans in the coastal waters of American Samoa and other islands in the tropical South Pacific has not been established (Dolar, 2005).

## SEA TURTLES

Green (*Chelonia mydas*) and hawksbill (*Eretmochelys imbricata*) sea turtles are the most commonly occurring sea turtles in coastal waters of American Samoa, and are the only species known to nest on territorial beaches (Utzurrum, 2002). There have been occasional records of Olive Ridley turtles (*Lepidochelys olivacea*) and a single record of a leatherback (*Dermochelys coriaca*) from pelagic waters south of Swains Island.

Few systematically-collected data exist on abundances of turtles in the territory (Craig et al., 2004), but ongoing monitoring by the DMWR is expected to address these deficiencies. Their approach includes bi-monthly, timed, double-observer snorkel surveys at 10 representative sites around Tutuila Island. These data are augmented by collection of incidental sighting reports from other sources, as well as a nesting beach monitoring program.

American Samoan turtle populations are known to use the waters of other countries in the region. Adult green turtles satellite tagged at Rose Atoll generally migrate to Fiji (Craig et al., 2004). Ongoing DMWR satellite tagging has been focused on individuals from Tutuila. Between February 2006 and March 2007, an adult female hawksbill tagged from western Tutuila moved into pelagic waters to the east, then west to Samoa. Juvenile turtles, based on data from three hawksbills and one green, exhibit much more site fidelity, as all remained in territorial waters after they were tagged.

Mortality of turtles near Tutuila is not uncommon. For example, 11 dead sea turtles were recovered from January to August 2007. Necropsies performed on three green and four hawksbill turtle carcasses found fishing line and a hook in the intestines of one hawksbill and pieces of plastic and aluminum in one green turtle; the rest had no obvious cause of death and tissue samples have yet to be analyzed. Known threats to the sea turtle population in American Samoa include habitat destruction of nesting beaches by sand mining and seawall construction, mortality as a result of fishing activities, and the disorienting affects of street lights on nesting turtles and hatchlings.

### Summary of Data Gathered

Benthic communities are in relatively good condition, with a dominance of coralline algae, almost no brown macroalgae, and better average coral cover than most reefs in the region. They appear to be relatively resilient, having recovered at least partially from a series of major disturbances such as COTS infestations, hurricanes and mass coral bleaching. However, coral cover remains about half of values recorded before the COTS outbreak in the late 1970s. The two atolls differed from the high islands in coral genera, algae, and invertebrates. There are very few diurnal non-cryptic invertebrates on reef slopes, but some notable communities exist in Pago Pago Harbor, where nutrient levels have improved but are still high enough to support significant plankton populations and non-toxic red tide blooms. There is significant sediment stress within some bays including the harbor, but reef slopes show relatively little impact. Diseases have only had relatively minor impacts so far. Mass coral bleaching has had some impacts, and now appears to be an annual event in small back reef pools. Water quality on the outer reef slopes is generally good, but significant effects of nonpoint pollution can be detected. Coral reef fish populations appear to be relatively healthy overall, maintaining relatively constant populations over the past thirty years. During this time, commercial and subsistence fishing effort and catch has declined to a low level, and the release from fishing pressure may increase reef fish populations in the future. Fish communities continue to be dominated by small and medium sized herbivorous fish, especially damselfish, surgeonfish and parrotfish. These herbivores aid in controlling algal cover which in turn promotes coral growth and health. Surveys with multibeam sonar have found many small banks on the shelf around Tutuila, and submersible exploration has found a deep limestone escarpment at the edge of the shelf.

## CURRENT CONSERVATION MANAGEMENT ACTIVITIES

The American Samoa Government coordinates territorial coral reef management activities via the Coral Reef Advisory Group (CRAG). This group comprises both territorial and federal agencies including the American Samoa Government Department of Commerce (ASDOC), which houses the American Samoa Coastal Management Program and Fagatele Bay National Marine Sanctuary, DMWR, ASEPA, American Samoa Community College and NPAS. These agencies collaborate to plan and implement actions related to the management of the territory's coral reefs.

The United States Coral Reef Initiative has been instrumental in supporting the territory in its coral reef conservation activities. Annual Coral Reef Management and Monitoring grants have provided managers and scientists in American Samoa with tools, staff, funds and equipment with which to accomplish key research and management projects. Territorial programs have benefited greatly from this support.

### *GIS Program*

Geographical Information System (GIS) technology is used by American Samoa natural resource and environmental agencies for planning, analysis and dissemination of information. CRAG member agencies have utilized GIS tools to support their local action strategies and as a way to coordinate activities of government agencies, community leaders, special interest groups, communities, or contractors during the planning process. ASDOC has developed an integrated GIS system as part of its information dissemination and analysis efforts. The ASDOC GIS system assists the Coastal Management Program with the identification of secondary and cumulative environmental impacts, development of goals, objectives, plan strategies and implementation, program management and forecasting of needs, and development trends, in addition to providing various maps and graphics; the system is updated with data products and IKONOS and other imagery inputs as they become available.

ASDOC's GIS information includes NOAA's Environmental Sensitivity Index (ESI) maps that systematically compile information in standard formats for coastal shoreline sensitivity, biological resources, and human-use patterns. ESI maps are useful for identifying sensitive resources so that protection priorities can be established. The ESI has been converted into a simplified format, making the data readily available to interested parties. ASEPA has used GIS technology to map existing pig farms on Tutuila for education and compliance purposes.

A number of GIS tools have been developed by DMWR for assistance in management. The Protected Areas Network Design Application for ArcGIS, was developed to provide a user friendly framework and interface to explore different hypothetical configurations of a system of marine protected areas (MPAs) in the territory.

### Mapping Data

In support of the U.S. Coral Reef Task Force's mission to "produce comprehensive digital maps of all shallow (<30 m) U.S. coral reef ecosystems and characterize priority moderate-depth reef systems by 2009," NOAA has developed a comprehensive mapping program in the Pacific. As discussed in the 2005 American Samoa State of the Reefs chapter (Craig et al., 2005), NOAA's CCMA-BB produced a shallow water (0-30 m) benthic habitat analysis from IKONOS satellite imagery (Figure 10.48). The resulting maps are also available online at: http://biogeo.nos.noaa.gov/products/biogeography/us_pac_terr/index.htm.

Academia has contributed substantially to American Samoa mapping efforts, with funding from the National Science Foundation and NOAA. In 2001 and 2002, researchers at Oregon State University (OSU) and the University of South

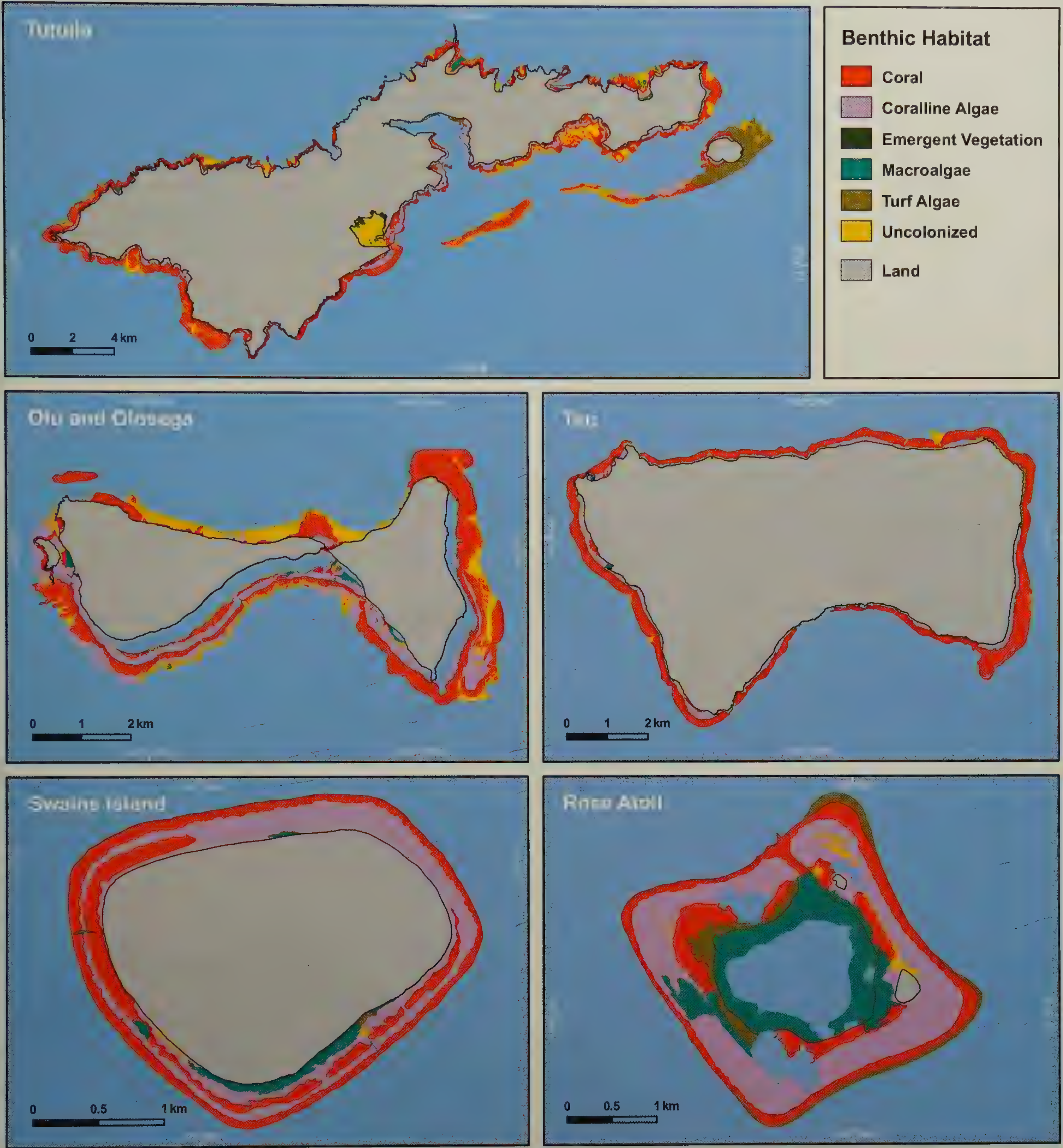

Tutuila
0 2 4 km
Benthic Habitat
Coral
Coralline Algae
Emergent Vegetation
Macroalgae
Turf Algae
Uncolonized
Land
Ofu and Olosega
0 1 2 km
Tau
0 1 2 km
Swains Island
0 0.5 1 km
Rose Atoll
0 0.5 1 km

*Figure 10.48. Nearshore benthic habitat maps were developed by CCMA-BB based on visual interpretation of IKONOS satellite imagery. Source: CCMA-BB, 2005.*

Florida (USF) extended shallow-water mapping to moderate depths (about 3-150 m) with multibeam surveys at Fagatele Bay, Taema Bank, Fagaitua Bay, Pago Pago harbor, Vatia Bay, Coconut Point and portions of the National Park, using a Kongsberg Simrad EM3000 multibeam sonar. Deep water (>100 m) multibeam mapping was conducted around Tutuila by OSU and USF scientists aboard the R/V *Revelle*, using a portable Kongsberg Simrad EM120 multibeam sonar, during a Scripps Drift Expedition (http://nsdl.sdsc.edu/cruises/DRFT10RR.html) in March 2002. These data are available at: http://dusk.geo.orst.edu/djl/samoa/. In July 2005, the Hawaii Undersea Research Laboratory's (HURL) R/V *Ka'imikai-O-Kanaloa* (*KOK*), with a SeaBeam 210, completed additional bathymetric surveys and submersible dives to fill deep water mapping gaps around Tutuila. In April 2005, other deep water opportunistic mapping was combined with the ALIA Expedition aboard the University of Hawaii's (UH) R/V *Kilo Moana* (Kongsberg Simrad EM1002 and EM120) to map most of the 100 m contour around the Samoan Hotspot (http://earthref.sdsc.edu/ERESE/projects/ALIA).

NOAA's PIFSC-CRED initiated a complementary moderate-depth (approximately 10–3,000 m) multibeam mapping program in 2001. The program first conducted multibeam surveys to survey the banktops of the Manua Islands and 60% of Tutuila in 2004 with the NOAA Ship *Oscar Elton Sette* and the 8 m R/V *Acoustic Habitat Investigator* (*AHI*). In 2006, PIFSC-CRED returned to American Samoa with the NOAA Ship *Hi'ialakai*, equipped with two Kongsberg Simrad multibeam sonars: a 30-kHz EM300 with mapping capability from about 100-3000+ m and a 300-kHz EM3002D with mapping capability from about 5-150 m. The R/V *AHI* has a 240-kHz Reson 8101ER with mapping capability from about 5-300 m. Both vessels have Applanix POS/MV motion sensors, which provide navigation and highly accurate readings of the vessel motion in all axes. Bathymetric surveys were completed in 2006 and gridded data are available from http://www.soest.hawaii.edu/pibhmc/pibhmc_amsamoa.htm. Supplementary optical validation data were collected by PIFSC-CRED in 2004 and 2006 using towed and drop camera systems. Additionally, three submersible dives were conducted from the *KOK* in July 2005 at Fagatele Bay and Taema Bay, recording video, photographs, positional tracking, and scientists' field logs. The cruise report and resulting data from the expedition may be found at http://dusk.geo.orst.edu/djl/samoa/.

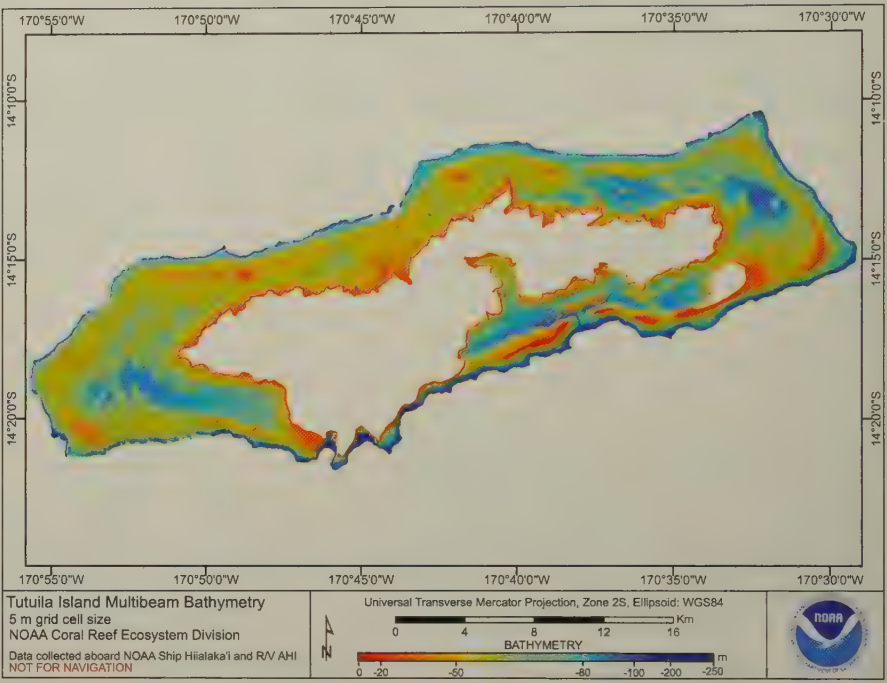

170°55'0"W
170°50'0"W
170°45'0"W
170°40'0"W
170°35'0"W
170°30'0"W
14°10'0"S
14°15'0"S
14°20'0"S
Tutuila Island Multibeam Bathymetry
5 m grid cell size
NOAA Coral Reef Ecosystem Division
Data collected aboard NOAA Ship Hiialaka'i and R/V AHI
NOT FOR NAVIGATION
Universal Transverse Mercator Projection, Zone 2S, Ellipsoid: WGS84
0 4 8 12 16 Km
BATHYMETRY
0 -20 -50 -80 -100 -200 -250 m
N
NOAA

Figure 10.49. Bathymetric information for Tutuila. Source: Brainard et al., in press.

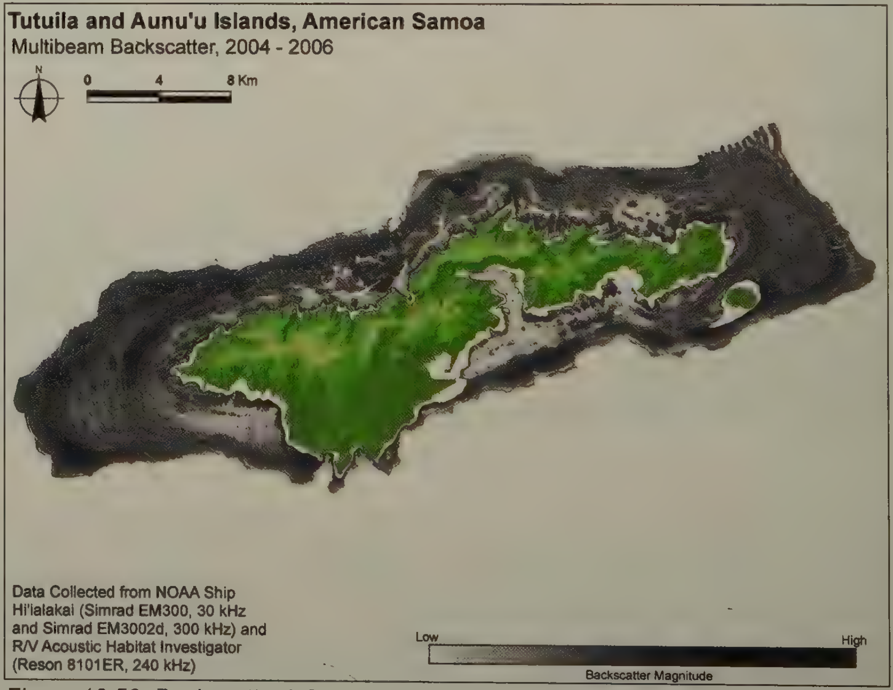

Tutuila and Aunu'u Islands, American Samoa
Multibeam Backscatter, 2004 - 2006
N
0 4 8 Km
Data Collected from NOAA Ship Hi'ialakai (Simrad EM300, 30 kHz and Simrad EM3002d, 300 kHz) and R/V Acoustic Habitat Investigator (Reson 8101ER, 240 kHz)
Low
High
Backscatter Magnitude

Figure 10.50. Backscatter information for Tutuila. Source: Brainard et al., in press.

Bathymetric data from 2004 and 2006 PIFSC-CRED *Hi'ialakai* and *AHI* surveys provide nearly complete coverage of the seafloor between depths of 10 m and 1000 m (Figure 10.49) at the following locations: Tutuila and Aunuu Islands, Ofu and Olosega Islands, Tau Island, Rose Atoll, Swains Island, Northeast Bank, Two Percent Bank and Vailuluu Seamount. The remaining unsurveyed shallow to moderate water areas are small gaps between swaths offshore.

Bathymetric grids at various resolutions and other data are updated as mapping, data processing, product and metadata generation, and interpretation are completed. High resolution bathymetric data provide baseline depth data, as well as visual indications of the nature of the seafloor. One of the important characteristics of this complex bank structure is of the abundance of hard, probably carbonate structures that may contain live coral. Concentrations exist around the outer edges of the bank, where there appears to be a relict fringing or barrier reef with ridge-like structures as shallow as 20 m. On the banks, but inside of the outermost barrier, depths range from 20–100 m and include many isolated high features.

Multibeam backscatter data (Figure 10.50) provide information about the hardness and roughness of the seafloor. High backscatter returns (dark) indicate hard substrate, while lower returns (light) indicate softer substrate. Backscatter has been processed for the Manua Group, Tutuila and Aunuu and are available for download at http://www.soest.hawaii.edu/pibhmc/. The backscatter returns suggest that the area northwest of Masefau Bay and Pago Pago Harbor are predominantly mud. Other areas (e.g., the offshore bank east of Tutuila) that return mixed backscatter signatures indicate potential coral habitat with pockets of unconsolidated sediments. Products that describe the benthic geomorphology (e.g., slope, rugosity, and Bathymetric Position Index) are derived from bathymetry data to describe seafloor characteristics that may influence benthic habitat utilization patterns. Tutuila shows high rugosity in many areas of the bank top and outer barrier reef, corresponding to areas of high bathymetric complexity and possible coral presence.

Optical validation data that have been collected at Tutuila aid scientists in interpretation of seafloor characteristics. Fifty-two video segments and 131 still photographs have been interpreted according to a benthic habitat classification scheme that was designed to include indications of substrate, living cover, coral type and other factors that may influence habitat utilization, as documented at ftp://soest.hawaii.edu/pibhmc/website/webdocs/webtext&figures/bh_class_codes.htm. Optical validation from the HURL submersible dives on PISCES V in July 2005 revealed valuable geological and biological features as deep as 460 m that are not able to be seen with any other methods currently used for undersea research. Integration of these data with bathymetry, backscatter, derived products and other optical validation information help identify significant deep-water coral reef habitats and areas of high biodiversity to support conservation and management.

### Marine Protected Areas Program

A territorial Marine Protected Area (MPA) Network strategy was finalized and adopted in 2007. The MPA Network Strategy aims to link American Samoa's MPA programs and agencies in an effort to better protect and manage marine resources. Existing MPA efforts in the territory encompass several levels: federal MPAs (Rose Atoll National Wildlife Refuge, Fagatele Bay National Marine Sanctuary, NPAS) territorial special management areas (Nu'uuli Pala wetlands, Pago Pago Harbor, Leone Pala wetlands), territorial MPAs (Ofu Vaoto Marine Park); local community-based MPAs co-managed by DMWR (Poloa, Alofau, Vatia, Aua, Masausi, Amaua-Auto, Fagamalo, Aoa, Matuu-Faganeanea and Masefau), and DMWR's no-take MPA program. In addition, the MPA Network will work with independent Samoa to better coordinate efforts and work towards developing regional MPA networks. The information provided below highlights the MPA programs administered by DMWR.

#### *No-take Program*

DMWR received increased support in 2005 to begin implementing the former governor's 20% no-take MPA declaration. The MPA program aims to create new no-take areas in order to ensure various and diverse marine habitats and spawning stocks are available to populate reefs regularly and after disasters. No-take program objectives are to gather diversity and spawning stock data; develop and conduct socioeconomic surveys; and educate the community about the benefits of developing no-take MPAs.

#### *Community-Based Fisheries Management Program*

Based on an initiative of community-based fisheries management reserves in the neighboring country of Samoa, the American Samoan government has implemented a similar effort to incorporate and utilize the distinctive Samoan culture in resource protection. American Samoa is unique within the U.S. in that villages have maintained virtually all marine and land tenure systems. As such, the Community-based Fisheries Management Program (CFMP) administered through DMWR works with individual village communities to identify resource trends and potential problems, and develop management plans that are locally appropriate and acceptable to the communities.

All of the CFMP reserve sites were established and managed principally to support the continued sustainable extraction of renewable living resources (e.g., fish, shellfish) within or outside the MPA by protecting important habitat and spawning, mating or nursery grounds; or providing harvest refugia for bycatch species. These MPAs also prohibit the extraction or destruction of natural or cultural resources within the MPA boundaries and restrict access and/or other activities that may adversely impact resources, processes, and qualities, or the ecological or cultural services they provide.

Each of the sites prohibits resource extraction with the exception of subsistence fishing for cultural practices in select instances. Village members can still utilize the resources for recreational and educational purposes. At times certain areas of the reef will be opened for use by elders in the village through the permission of the village council and as outlined in the individual MPA's management plan. Closure of the sites expires after three years, at which time the village reviews the management plan and its effects and decides if they would like to continue it with the same regulations, alter the regulations or discontinue the program. Some villages select to open the sites temporarily for fishing before closing them for an extended period. DMWR is moving toward discussions of more long-term or permanent closures for community sites.

Management plan implementation is carried out by the villages with assistance from DMWR. Management efforts for the sites include monitoring, enforcement, and public awareness. A compendium of village by-laws regulating the use of a village marine protected area has been drafted under DMWR code and is in the final stages of approval before adoption.

#### *CFMP Public Participation*

This program was developed to encourage communities to actively manage their local resources in collaboration with DMWR through a series of regular meetings and training programs. Because it is based on public involvement, the program would not succeed without significant public support. Regular meetings are held between stakeholder groups. A Fisheries Management Advisory Committee composed of DMWR and selected members of the chiefs and untitled men's group works together to compile information gathered at group meetings and from a baseline questionnaire form and develop a Fisheries Management Plan for the village. Efforts to raise the awareness about the MPAs among villagers mostly take place during village meetings where there is an exchange of information between DMWR staff and villagers.

To help local villagers monitor and enforce sites, DMWR has provided training workshops in monitoring, boating safety, and equipment for the community. Information sheets on fisheries, corals, seaweeds, mangroves, dynamite fishing, and bleaching have been distributed in conjunction with press releases and radio announcements. To encourage stakeholder participation, the use of participatory tools for information gathering, planning, decision-making, monitoring and evaluation was included in Participatory Learning and Action (PLA) village workshops hosted in partnership with local National Marine Fisheries staff. PLA is a community action program that engages all sectors of the community, especially women and youth. The PLA philosophy is based on involving the community in information gathering, development, and implementation phases to empower people with responsibility and accountability for their actions.

### *Education and Outreach*

In 2006, as part of its education and outreach initiative, CRAG launched the American Samoa Rare Pride Campaign featuring the green sea turtle as its flagship species. Through the development process, the American Samoa Rare Pride Campaign successfully engaged stakeholders in developing a campaign that addresses human behavior, develops innovative ways to promote environmental stewardship and creates new partnership opportunities. Successful campaign projects include a community college internship program and a community reef watcher program. The reef watcher program solicits village volunteers to monitor their village beaches and report illegal activities to authorities.

Outreach staff from resource agencies including the CRAG, DMWR, ASCMP and Fagatele Bay National Marine Sanctuary collaborate on student coral reef education and outreach projects through the Coral Reef Outreach and Education (CROE) group. The purpose of CROE's efforts is to improve environmental literacy for students, provide resources for teachers, increase student interest in marine science and provide education and outreach to the communities.

### *American Samoa Marine Laboratory*

A facility plan for a territorial marine laboratory was prepared in 2003. A consultant is currently preparing a business plan for the marine lab that will describe key activities, governance structures, implementation plans and staffing and operational requirements for marine lab development and the first five years of sustainable operation. The consultant is also investigating the potential for partnerships with specific government and academic institutions to utilize the facility and enhance its research and education potential.

### *Marine Aquaculture*

Marine aquaculture is recognized as a means to alleviate pressures in nearshore reef communities through stock enhancement efforts as well as through providing alternative employment opportunities to fishermen. In doing so, effort is redirected from fishing to cultural practices. Current efforts are being focused on completing a giant clam hatchery in Tutuila and initiating grow-out facilities in the economically depressed Aunuu and Manua Islands. Together, these facilities seek to culture local giant clams for one of three markets: 1) the marine ornamental industry; 2) local markets and restaurants; and 3) stock enhancement efforts. The UH Sea Grant College Program has provided an extension agent to work on marine aquaculture projects. In addition to giant clams, corals and sponges are potential candidate species for marine aquaculture throughout American Samoa.

## OVERALL CONCLUSIONS AND RECOMMENDATIONS

The reef benthic communities of American Samoa are in better condition than most Pacific and almost all western Atlantic reefs, with higher coral cover than some other nearby Pacific reefs, and much lower cover of brown macroalgae than many of the western Atlantic reefs and Pacific reefs. Major disturbances have been produced by mass coral bleaching events, hurricanes, COTS outbreaks and extreme low tide events, but the Territory's reefs appear to be relatively resilient. Pago Pago Harbor has lost most of its coral reefs, and plankton levels remain high. Diseases and sediment present threats but have not had major effects so far. The coral reef fish community, while having lower overall biomass than some reefs in the region, still appears to be fairly stable. Biomass levels have remained relatively unchanged over the past 30 years, while fishing effort and catch have declined to low levels. Small and medium sized herbivorous fish are relatively abundant. Some larger species of reef fish, however, appear to be uncommon or rare which has prompted the government to grant a number of species full protection from harvest.

There are significant opportunities for important research on topics such as the corals in Ofu lagoon pools that are resistant to bleaching, annual mass coral bleaching in back reef pools, and coral diseases. Surveys are needed to document special communities such as sponges and sea fans in deeper parts of the harbor and nocturnal invertebrates, and determine the causes of non-toxic red tide blooms in the harbor. Additional information on specific reef fish species is needed in order to determine the status of the populations and to elucidate the effects of habitat availability, larval supply and connectivity, pollution, eutrophication and other factors. Fish populations on outer banks and in deeper waters also need to be surveyed. Studies of the effectiveness of MPAs in increasing fish populations within and outside MPA boundaries should be undertaken along with human dimension studies that can determine culturally appropriate ways to integrate traditional practices into the implementation of MPAs in American Samoa. Human dimension studies could also improve the design of regulations to maximize compliance.

## REFERENCES

Aeby, G.S. 2006. Baseline levels of coral disease in the Northwestern Hawaiian Islands. Atoll Res. Bull. 543: 471-488.

Aeby, G., T. Work, and D. Fenner. 2006. Coral and crustose coralline algae disease on the reefs of American Samoa. Report to Coral Reef Advisory Group, American Samoa Government. 25 pp.

Andrews, Z. 2004. Evaluation of the effects of community-based fisheries management on coral reef communities of American Samoa. Masters of Science Thesis, University of Wales, Bangor, UK.

Barshis, D. Department of Zoology, University of Hawaii at Manoa. Honolulu, HI. Personal communication.

Birkeland, C. Department of Zoology, University of Hawaii at Manoa. Honolulu, HI. Personal communication.

Birkeland, C., R.H. Randall, A.L. Green, B.D. Smith, and S. Wilkins. 2003. Changes in the coral reef communities of Fagatele Bay National Marine Sanctuary and Tutuila Island (American Samoa), 1982-1995. Report for US Department of Commerce and American Samoa Government. Fagatele Bay National Marine Sanctuary Science Series 2003-1. 237 pp.

Brainard, R., J. Asher, S. Balwani, P. Craig, S. Ferguson, J. Gove, J. Helyer, R. Hoeke, J. Kenyon, M. Lammers, E. Lundblad, F. Mancini, J. Maragons, J. Miller, R. Moffitt, S. Myhre, M. Nadon, B. Richards, J. Rooney, R. Schroeder, E. Smith, M. Timmers, B. Vargas-Angel, O. Vetter, S. Vogt, and P. Vroom. In press. American Samoa Report of the PIFSC-CRED monitoring program.

Brokovich, E., A. Baranes, and M. Goren. 2006. Habitat structure determines coral reef fish assemblages at the northern tip of the Red Sea. Ecological Indicators 6(3):494-507.

Brown, P. National Parks of American Samoa. Pago Pago, American Samoa. Personal communication.

Brown, B.E. and J.C. Ogden. 1993. Coral Bleaching. Sci. Am. 268(1): 64-70.

CCMA-BB. 2005. Shallow-water Benthic Habitats of American Samoa, Guam, and the Commonwealth of the Northern Mariana Islands. NOAA Technical Memorandum NOS NCCOS 8. Silver Spring, MD. 126 pp. http://ccma.nos.noaa.gov/products/biogeography/us_pac_terr/index.htm.

Chamberlin, R.T. 1921. The geological interpretation of the coral reefs of Tutuila, Samoa. Carnegie Institute Washington Yearbook 19: 194-195.

Coles, S.L. and D.G. Seapy. 1998. Ultra-violet absorbing compounds and tumorous growths on acroporid corals from Bandar Khayran, Gulf of Oman, Indian Ocean. Coral Reefs 17: 195-198.

Coles, S.L., P.R. Reath, P.A. Skelton, V. Bonito, R.C. DeFelice, and L. Basch. 2003. Introduced marine species in Pago Pago Harbor, Fagatele Bay and the national park coast, American Samoa. Bish. Mus. Tech. Rep. 26. 182 pp.

Coutures, E. 2003a. The biology and artisanal fishery of lobsters of American Samoa. Department of Marine and Wildlife Resources Report Series 103, Government of American Samoa. Pago Pago, American Samoa. 67 pp.

Coutures, E. 2003b. The shoreline fishery of American Samoa: analysis of 1 year data and implementation of a new sampling protocol. Department of Marine and Wildlife Resources Report Series 102, Government of American Samoa . Pago Pago, American Samoa. 22 pp.

Craig, P. National Park of American Samoa. Tutuila, American Samoa. Personal communication.

Craig, P. 2005. Natural History Guide to American Samoa, 2nd Edition. National Park of American Samoa, Department of Marine and Wildlife Resources and American Samoa Community College. Pago Pago, American Samoa. 96 pp.

Craig, P., C. Birkeland, and S. Belliveau. 2001. High temperatures tolerated by a diverse assemblage of shallow-water corals in American Samoa. Coral Reefs 20(1): 185-189.

Craig, P., D. Parker, R. Brainard, M. Rice, and G. Balazs. 2004. Migrations of green turtles in the central South Pacific. Biol. Conserv. 116: 433-438.

Craig, P., G. DiDonato, D. Fenner, and C. Hawkins. 2005. The State of Coral Reef Ecosystems of American Samoa. pp. 312-337. In: J.E. Waddell (ed.). The State of Coral Reef Ecosystems of the United States and Pacific Freely Associated States: 2005. NOAA Technical Memorandum NOS NCCOS 11. Silver Spring, MD. 522 pp.

Craig, P. and A. Green 2005. Overfished coral reefs in American Samoa: no quick fix. Reef Encounter 33: 21-22.

Davis, W.M. 1921. The coral reefs of Tutuila. Science 53(1382): 559-565.

Dawson, E.Y. 1961. The rim of the reef. Nat. Hist. 70(6): 8-17.

Dolar, M.L. 2005. Cetaceans of American Samoa. Department of Marine and Wildlife Resources, Government of American Samoa. Pago Pago, American Samoa. 24 pp.

Eldredge, L.G. and N.L. Evenhuis. 2003. Hawaii's Biodiversity: A Detailed Assessment of the Numbers of Species in the Hawaiian Islands. Bish. Mus. Occ. Pap. 76: 1-28.

Fabricius, K. and G. De'ath. 2001. Environmental factors associated with the spatial distribution of crustose coralline algae on the Great Barrier Reef. Coral Reefs 19: 303-309.

Fenner, D. and B. Carroll. In review. Results of the American Samoa Territorial Coral Reef Monitoring Program for 2006. Department of Marine and Wildlife Resources, Government of American Samoa. Pago Pago, American Samoa.

Fisk, D. Unaffiliated scientist. Geneva, Switzerland. Personal communication.

Fisk, D. and C. Birkeland. 2002. Status of coral communities on the volcanic islands of American Samoa. Department of Marine and Wildlife Resources, Government of American Samoa. Pago Pago, American Samoa. 135 pp.

Friedlander, A. and E.E. DeMartini. 2002. Contrasts in density, size, and biomass of reef fishes between the northwestern and main Hawaiian Islands: effects of fishing down apex predators. Mar. Ecol. Prog. Ser. 230: 253-264.

Friedlander, A., G. Aeby, R. Brainard, A. Clark, E. DeMartini, S. Godwin, J. Kenyon, R. Kosaki, J. Maragos, and P. Vroom. 2005. The state of coral reef ecosystems of the Northwestern Hawaiian Islands. pp. 270-311. In: J.E. Waddell (ed.). The State of Coral Reef Ecosystems of the United States and Pacific Freely Associated States: 2005. NOAA Technical Memo NOS NCCOS 11. Silver Spring, MD. 522 pp.

Garrison, V., K. Kroeger, D. Fenner, and P. Craig. 2007. Identifying nutrient sources to three lagoons at Ofu and Olosega, American Samoa using delta15N of benthic macroalgae. Mar. Poll. Bull. 54: 1830-1838.

Glynn, P.W. 1996. Coral reef bleaching: facts, hypotheses and implications. Global Change Biol. 2: 495-509.

Goreau, T.F. 1959. The ecology of Jamaican coral reefs I. species composition and zonation. Ecology 40(1): 67-90.

Goreau, T.J. and R. Hayes. 1994. Survey of coral reef bleaching in the South Central Pacific during 1994: Report to the International Coral Reef Initiative. Global Coral Reef Alliance. Chappaqua, New York. 201 pp.

Green, A.L. 1996. Status of the coral reefs of the Samoan Archipelago. Department of Marine and Wildlife Resources Report Series, Government of American Samoa. Pago Pago, American Samoa. 120 pp.

Green, A.L. 2002. Status of coral reefs on the main volcanic islands of American Samoa: a re-survey of long-term monitoring sites (benthic communities, fish communities, and key macroinvertebrates). Department of Marine and Wildlife Resources, Government of American Samoa. Pago Pago, American Samoa. 87 pp.

Green, A., C. Birkeland, and R. Randall. 1999. Twenty years of disturbance and change in Fagatele Bay National Marine Sanctuary, American Samoa. Pac. Sci. 53: 376-400.

Green, A. and P. Craig. 1999. Population size and structure of giant clams at Rose Atoll, an important refuge in the Samoan Archipelago. Coral Reefs 18: 205-211.

Green, A., K. Miller, and C. Mundy. 2005. Long term monitoring of Fagatele Bay National Marine Sanctuary, Tutuila, American Samoa: results of surveys conducted in 2004, including a re-survey of the historic Aua Transect. Report for U.S. Department of Commerce and the American Samoa Government. 93 pp.

Grigg, R.W. 1998. Holocene coral reef accretion in Hawaii: a function of wave exposure and sea level history. Coral Reefs 17: 263-272.

Hoegh-Guldberg, O. 1999. Climate change, coral bleaching and the future of the world's coral reefs. Mar. Freshw. Res. 50(8): 839-866.

Houk, P. 2005. Assessing the effects of non-point source pollution on American Samoa's coral reef communities II. Technical Report for American Samoa Environmental Protection Agency. Pago Pago, American Samoa. 16 pp.

Houk, P., G. DiDonato, J. Iguel, and R. van Woesik. 2005. Assessing the effects of non-point source pollution on American Samoa's coral reef communities. Environ. Monit. Assess. 107: 11-27.

Houk, P. and C. Musburger. 2007. Assessing the effects of non-point source pollution on American Samoa's coral reef communities. Technical Report for American Samoa Environmental Protection Agency. Pago Pago, American Samoa. 33 pp.

Kilarski, S., D. Klaus, J. Lipscomb, K. Matsoukas, R. Newton, and A. Nugent. 2006. Decision support for coral reef fisheries management: community input as a means of informing policy in American Samoa. M.S. Thesis. University of California at Santa Barbara, Santa Barbara, CA. 132 pp.

Kolinski, S.P. 2006. An assessment of corals five years following transplantation at Aua, Tutuila, American Samoa. Pacific Islands Regional Office, NOAA National Marine Fisheries Service (NMFS). Honolulu, HI. 9 pp.

Lapointe, B.E. 1997. Nutrient thresholds for bottom-up control of macroalgal blooms on coral reefs in Jamaica and Southeast Florida. Limn. Ocean. 42(5): 1119-1131.

Lara, E.N. and E.A. Gonzalez. 1998. The relationship between reef fish community structure and environmental variables in the southern Mexican Caribbean. J. Fish Biol. 53: 209-221.

Littler, M.M. and D.S. Littler. 1985. Factors controlling relative dominance of primary producers on biotic reefs. pp. 35-40. In: C. Gabrie and B. Salvat (eds.). Proceedings of the 5th International Coral Reef Congress, Vol. 4. Tahiti, French Polynesia. 581 pp.

Littler, M.M. and D.S. Littler. 1995. Impact of CLOD pathogen on Pacific coral reefs. Science 267(5202): 1356-1360.

Littler, M.M. and D.S. Littler. 1998. An undescribed fungal pathogen of reef-forming crustose coralline algae discovered in American Samoa. Coral Reefs 17: 144.

Liu, J. 2005. Ecotourism Plan for American Samoa 2005-2009: Final. Prepared for American Samoa Department of Commerce. School of Travel Industry Management, University of Hawaii at Manoa. Honolulu, HI. 259 pp.

Madrigal, L.G. 1999. Field guide of shallow water marine invertebrates of American Samoa. Division of Curriculum and Instruction. American Samoa Department of Education. Pago Pago, American Samoa. 132 pp.

McConnaughey, J. 1993. The shoreline fishery of American Samoa in FY 92. Department of Marine and Wildlife Resources Report Series 41, Government of American Samoa. Pago-Pago, American Samoa.

Michalek-Wagner, K. and B.L. Willis. 2001. Impacts of bleaching on the soft coral *Lobophytum compactum*. I. Fecundity, fertilization and offspring viability. Coral Reefs 19: 231-239.

Mielbrecht, E. Emerald Coast Environmental Consulting. Washington, DC. Personal communication.

Mundy, C. 1996. A Quantitative Survey of the Corals of American Samoa. Report to the Department of Marine and Wildlife Resources, Government of American Samoa. Pago Pago, American Samoa. 25 pp.

Nagaoka, L. 1992. Faunal assemblages from the To'aga site. pp: 189-216 In: P.V. Kirch and T.L. Hunt (eds.). The To'aga site: three millennia of Polynesian occupation in the Manua Islands, American Samoa. Archaeological Research Facility, University of California at Berkeley. Berkley, CA. 248 pp.

Nguyen, L.V. and H.K. Phan. 2007 Distribution and factors influencing on structure of reef fish communities in Nha Trang Bay Marine Protected Area, South-Central Vietnam. Environ. Biol. Fish. (online). 16 pp. http://www.springerlink.com/content/45wj3815674564vr/fulltext.pdf.

Page, M. 1998. The biology, community structure, growth and artisanal catch of parrotfishes in American Samoa. Report to the Department of Marine and Wildlife Resources, Government of American Samoa. Pago Pago, American Samoa. 87 pp.

Pandolfi J.M., G. Llewellyn, and J.B.C. Jackson. 1999. Pleistocene reef environments, constituent grains, and coral community structure: Curacao, Netherlands Antilles. Coral Reefs 18: 107-122.

Paulay, G. (ed.). 2003. The marine biodiversity of Guam and the Marianas. A Journal of the University of Guam, Vols. 35-36. University of Guam Press, Guam. 682 pp.

Pinca, S., M. Beger, D. Jacobson, and T. Keju. 2005. The State of Coral Reef Ecosystems of the Republic of the Marshall Islands. pp. 373-386. In: J.E. Waddell (ed.). The state of coral reef ecosystems of the United States and Pacific Freely Associated States: 2005. NOAA Technical Memorandum NOS NCCOS 11. Silver Spring, MD. 522 pp.

Ponwith, B.J. 1991. The inshore fishery of American Samoa: a 12-year comparison. Department of Marine and Wildlife Resources Biological Report Series 22, Government of American Samoa. Pago Pago, American Samoa. 51 pp.

Preskitt, L.B., P.S. Vroom, and C.M. Smith. 2004. A rapid ecological assessment (REA) quantitative survey method for benthic algae using photo quadrats with SCUBA. Pac. Sci. 58: 201-209.

Richard, G. 1985. Fauna and flora, a first compendium of French Polynesia sea-dwellers. pp. 379-520. In: B. Delesalle, R. Galzin, and B. Salvat (eds.). Proceedings of the 5th International Coral Reef Congress, Vol 1. Tahiti, French Polynesia. 520 pp.

Robbins, J. and D.K. Mattila. 2006. Summary of humpback whale research in American Samoa, 2003-2005. Unpublished report to the Scientific Committee of the International Whaling Commission. The 58th Annual Meeting of the International Whaling Commission. St. Kitts and Nevis.

Rogers, C.S. 1990. Responses of coral reefs and reef organisms to sedimentation. Mar. Ecol. Prog. Ser. 62: 185-202.

Sabater, M.G. and S. Tofaeono. 2006. Spatial variation in biomass, abundance, and species composition of "key reef species" in American Samoa. Department of Marine and Wildlife Resources, Government of American Samoa. Pago Pago, American Samoa. 62 pp.

Sabater, M.G. and S. Tofaeono. 2007. Effects of scale and benthic composition on biomass and trophic group distribution of reef fishes in American Samoa. Pac. Sci. 61(4): 503-520.

Saucerman, S. 1995. The inshore fishery of American Samoa, 1991 to 1993. Department of Marine and Wildlife Resources Biological Report Series 77, Government of American Samoa. Pago Pago, American Samoa.

Skelton, P. 2003. Seaweeds of American Samoa. Prepared for Department of Marine and Wildlife Resources, Government of Samoa. International Ocean Institute and Oceania Research and Development Associates. Townsville, Australia. 103 pp.

Smith, L. Department of Zoology, University of Hawaii at Manoa. Honolulu, HI. Personal communication.

South Pacific Commission (SPC). 2005. Reef Fisheries Observatory, preliminary findings: a snapshot of the condition of coral reefs in Fiji Islands, French Polynesia, Kiribati, New Caledonia, Tonga and Vanuatu from 2002-2004. SPC Fisheries Newsletter 112: 2-5.

Steneck, R.S. 1997. Crustose corallines, other algal functional groups, herbivores and sediments: complex interactions along reef productivity gradients. pp. 695-700. In: H.A. Lessios and I.G. Macintyre (eds.). Proceedings of the 8th International Coral Reef Symposium, Vol.1. Panama City, Panama. 1040 pp.

Stevenson, C., L.S. Katz, F. Michelli, B. Boch, K.W. Heiman, C. Perle, K. Weng, R. Dunbar, and J. Witting. 2006. High apex predator biomass on remote Pacific Islands. Coral Reefs 26(1): 47-51.

Telesnicki, G.J. and W.M. Goldberg. 1995. Effects of turbidity on the photosynthesis and respiration on two South Florida reef coral species. Bull. Mar. Sci. 57(2): 527-539.

Ulijaszek, S.J. 2002. Modernization and the diet of adults on Rarotonga, the Cook Islands. Ecol. Food Nutr. 41: 203-228.

U.S. Census Bureau. 1990. Census of Population. American Samoa Department of Commerce. Pago Pago, American Samoa.

U.S. Census Bureau. 2000. Census of Population. American Samoa Department of Commerce. Pago Pago, American Samoa.

U.S. Environmental Protection Agency. 1997. Guidelines for preparation of the comprehensive state water quality assessments (305(b) Reports) and electronic updates. Assessment and Watershed Protection Division, Office of Wetlands, Oceans, and Watersheds, U.S. Environmental Protection Agency. Washington, DC. http://www.epa.gov/owow/monitoring/guidelines.html.

U.S. Environmental Protection Agency. 2002. Consolidated assessment and listing methodology, toward a compendium of best practices, 1st edition. Office of Wetlands, Oceans, and Watersheds, U.S. Environmental Protection Agency. Washington, DC. http://www.epa.gov/owow/monitoring/calm.html.

Utzurrum, R.C.B. 2002. Sea turtle conservation in American Samoa. pp. 33-36. In: I. Kinan (ed.). Proceedings of the western Pacific sea turtle cooperative research and management workshop. Western Pacific Regional Fishery Management Council. Honolulu, HI. 300 pp.

Utzurrum, R.C.B., J.O. Seamon, and K. Sehletz Saili. 2006. A comprehensive strategy for wildlife conservation in American Samoa. Department of Marine and Wildlife Resources, Government of American Samoa. Pago Pago, American Samoa. 109 pp.

Valiela I. 1995. Marine Ecological Processes, 2nd edition. Springer-Verlag, New York, NY. 686 pp.

Van Woesik, R. and T.J. Done. 1997. Coral communities and reef growth in the southern Great Barrier Reef. Coral Reefs 16: 103-115.

Vroom, P.S., K.N. Page, J.C. Kenyon, and R.E. Brainard. 2006. Algae-Dominated Reefs. Am. Sci. 94: 430-437.

Wass, R.C. 1977. Coral reef fish transect data set. Department of Marine and Wildlife Resources Biological Report Series, Government of American Samoa. Pago Pago, American Samoa.

Wass, R.C. 1982. Characterization of inshore Samoan fish communities. Department of Marine and Wildlife Resources Biological Report Series 6, Government of American Samoa. Pago Pago, American Samoa. 27 pp.

Wass, R.C. 1984. An annotated checklist of the fishes of Samoa. NOAA Technical Report NMFS SSRF 781. Seattle, WA. 43 pp.

Western Pacific Regional Fishery Management Council. 2007. Fisheries data from American Samoa fisheries. http://wpcouncil.org/AmericanSamoa.htm.

Whaylen, L. and D. Fenner. 2006. Report of 2005 American Samoa coral reef monitoring program (ASCRMP), expanded edition. Department of Marine and Wildlife Resources Report and Coral Reef Advisory Group, American Samoa. 64 pp.

Willis, B., C. Page, and E. Dinsdale. 2004. Coral disease on the Great Barrier Reef. pp. 69-104. In: E. Rosenberg and Y. Loya (eds.). Coral Health and Disease. Springer. Berlin, Heidelberg, New York. 488 pp.

World Health Organization (WHO). 2003. Diet, food supply and obesity in the Pacific. Regional Office for the Western Pacific. World Health Organization, Switzerland. 71 pp.

Work, T., S. Coles, and R. Rameyer. 2001. Johnston Atoll reef health survey. National Wildlife Health Center, Honolulu Field Station, U.S. Geological Survey. Honolulu, HI. 28 pp.

Work, T., S. Coles, and R. Rameyer. 2002. French Frigate Shoals reef health survey. U.S. Geological Survey National Wildlife Health Center, Hawaii Field Station. 25 pp.

Work, T., R.A. Rameyer, G. Takata, and M. Kent. 2003. Protozoal and epitheliocystis-like infections in the introduced blueline snapper *Lutjanus kasmira* in Hawaii. Dis. Aquat. Org. 37: 59-66.

Work, T. and R. Rameyer. 2005. Evaluating coral reef health in American Samoa. Coral Reefs 24: 384-390.

Work, T., G. Aeby, and S. Coles. In review. Distribution and morphology of growth anomalies in *Acropora* from across the Indo-Pacific. Dis. Aquat. Org.

Wright, D.J. 2005. Report of HURL Cruise KOK0510: Submersible Dives and Multibeam Mapping to Investigate Benthic Habitats of Tutuila, American Samoa. NOAA Office of Undersea Research Submersible Science Program, Hawaii Undersea Research Lab, University of Hawaii. 22 pp. http://dusk2.geo.orst.edu/djl/samoa/hurl/cruiseKOK0510_report.pdf.

Zeller, D., S. Booth, P. Craig, and D. Pauly. 2006. Reconstruction of coral reef fisheries catches in American Samoa, 1950-2002. Coral Reefs 25: 144-152.

# The State of Coral Reef Ecosystems of the Pacific Remote Island Areas

Joyce Miller[1,2], Jim Maragos[3], Russell Brainard[1], Jacob Asher[1,2], Bernardo Vargas-Ángel[1,2], Jean Kenyon[1,2], Robert Schroeder[1,2], Benjamin Richards[1,2], Marc Nadon[1,2], Peter Vroom[1,2], Amy Hall[1,2], Elizabeth Keenan[4], Molly Timmers[1,2], Jamison Gove[1,2], Ellen Smith[1,2], Jonathan Weiss[1,2], Emily Lundblad[1,2], Scott Ferguson[1], Frances Lichowski[1,2] and John Rooney[1,2]

## INTRODUCTION AND SETTING

This report is the third in a series of assessments of the current status of coral reef ecosystems in the Pacific Remote Island Areas (PRIA). PRIA are defined as isolated U.S. sovereign islands and atolls not within the jurisdiction of any U.S. state or territory. Seven of the eight PRIA (except Midway) are discussed in this chapter including: Howland, Baker and Jarvis Islands; Johnston, Palmyra, Kingman and Wake Atolls. Midway is included in the chapter on the Northwestern Hawaiian Islands (NWHI). Rose Atoll and Swains Island are a part of the Territory of American Samoa and are covered in the chapter on American Samoa.

The first State of the Reefs Report (Turgeon et al., 2002) provided a broad overview of the status of the seven islands, atolls and reefs covered in this chapter and concluded that "all the [PRIA] coral reefs are generally in excellent-to-good condition." In the second PRIA State of the Reefs Report, Brainard et al. (2005) identified specific threats to the coral ecosystems observed before 2005 and described the oceanographic and biological monitoring methods being applied across the PRIA. In addition, the 2005 report concluded that the coral reef ecosystems of the PRIA remained quite healthy and productive, with limited impacts noted from unauthorized fishing, abandoned WWII material and ship groundings. The report also recommended that Pacific Reef Assessment and Monitoring Program (RAMP) surveys of all PRIA continue on a biennial basis.

Six of the seven PRIA are National Wildlife Refuges (NWR) under the jurisdiction of the U.S. Fish and Wildlife Service (USFWS), Department of the Interior (DOI). Palmyra Atoll is unique in that part of it (Cooper Island) is privately owned by The Nature Conservancy (TNC), with the remainder of the atoll being managed and operated by the USFWS. Wake Atoll, the only PRIA that is not a NWR, is under the control of the DOI and operated by the U.S. Air Force, with a population of 150-250 Air Force personnel and contractors, who primarily provide infrastructure support. Wake has an active airstrip that is used mostly by the U.S. military as a refueling stop. Johnston, Kingman, Palmyra, Baker, Howland, Jarvis, and Rose (American Samoa) were proposed to be added to the U.S. Tentative List for World Heritage Sites and are now being evaluated as "Ramsar" (1971 Convention on Wetlands of International Importance at Ramsar, Iran) sites.

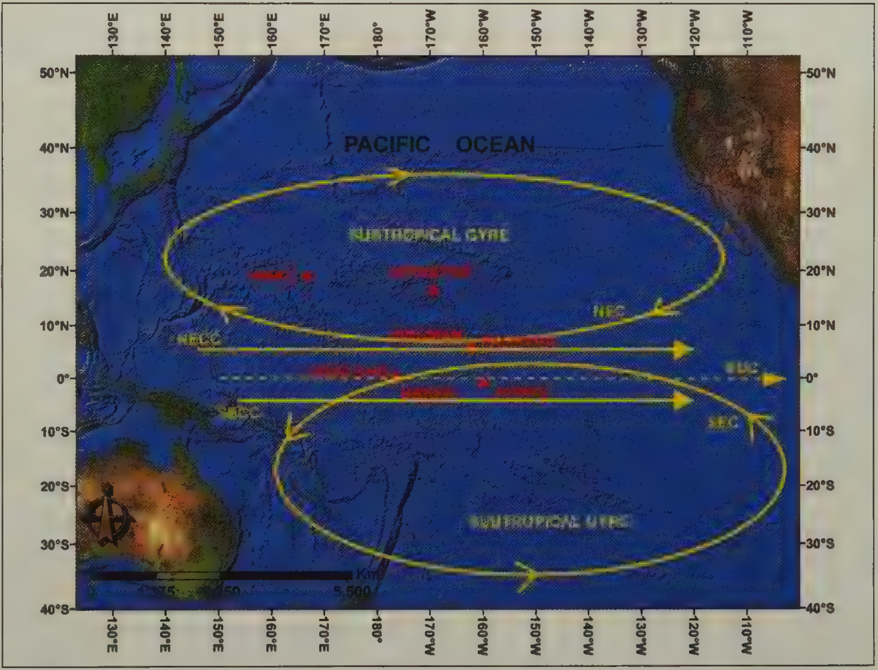


*Figure 11.1. Topographic map showing location in Pacific Ocean of the PRIA and major ocean currents in the region: North Equatorial Current (NEC), South Equatorial Current (SEC), North Equatorial Counter Current (NECC), South Equatorial Counter Current (SECC), Equatorial Undercurrent (EUC). Source: PIFSC-CRED.*

The seven islands and atolls of the PRIA discussed in this report are dispersed over a vast and remote area in the central Pacific Ocean and influenced by varying oceanographic and climatic conditions and processes (Figure 11.1).

From north to south (Figures 11.1 and 11.2):

**Wake Atoll** (19° 17'N, 166° 36'E) and **Johnston Atoll** (16° 45'N, 169° 31'W) are influenced primarily by easterly trade winds, the westward-flowing North Equatorial Current (NEC), and significant winter swell from the North Pacific. The climate is tropical and relatively dry with rainfall of generally less than 300 mm/year. Wake Atoll is the northernmost atoll of the Marshall Island seamount chain, while Johnston Atoll is considered by some to be the northernmost atoll of the Line Island Chain (although it is geographically closer and biologically more similar to the Hawaiian Archipelago).

---

1. NOAA National Marine Fisheries Service, Pacific Islands Fisheries Science Center, Coral Reef Ecosystem Division
2. Joint Institute for Marine and Atmospheric Research
3. U.S. Fish and Wildlife Service
4. NOAA Papahanaumokuakea Marine National Monument

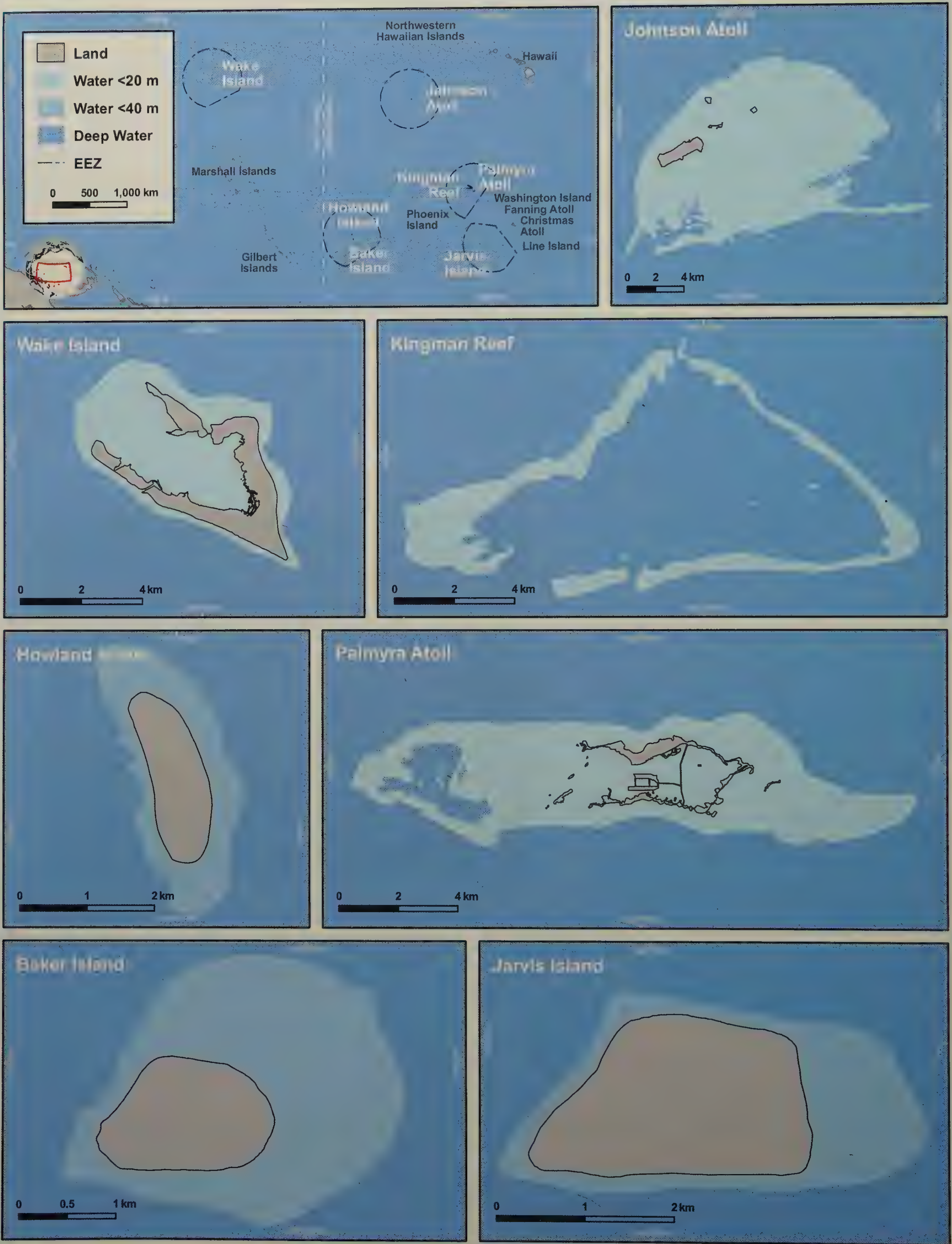

Land
Water <20 m
Water <40 m
Deep Water
EEZ
0 500 1,000 km
Wake Island
Northwestern Hawaiian Islands
Hawaii
Johnston Atoll
Marshall Islands
Kingman Reef
Palmyra Atoll
Washington Island
Fanning Atoll
Christmas Atoll
Line Island
Howland Island
Phoenix Island
Baker Island
Jarvis Island
Gilbert Islands
Johnston Atoll
0 2 4 km
Wake Island
0 2 4 km
Kingman Reef
0 2 4 km
Howland Island
0 1 2 km
Palmyra Atoll
0 2 4 km
Baker Island
0 0.5 1 km
Jarvis Island
0 1 2 km

*Figure 11.2. Locator map for the PRIA. Map: K. Buja.* **NOTE:** *Island/atoll/reef abbreviations in figures and tables are as follows: JOH=Johnson Atoll; WAK=Wake Island; BAK=Baker Island; HOW=Howland Island; JAR=Jarvis Island; PAL=Palmyra Atoll; ROS=Rose; and KIN=Kingman Reef.*

**Kingman Reef** (6°24′N 162°24′W) and **Palmyra Atoll** (5°52′N 162°6′W) are both influenced seasonally by the eastward-flowing NECC and the westward-flowing NEC. Weather and sea conditions at both atolls are strongly influenced by their location within the Intertropical Convergence Zone (ITCZ) during the summer months. When within the ITCZ, both atolls experience mostly light, variable winds, extremely high precipitation (4.5 m of rain per year at Palmyra) and a humid tropical climate. During the winter months, both atolls experience moderately strong easterly trade winds and seas. Both are part of the Line Islands seamount chain.

**Baker Island** (0°12′N 176°29′W), **Howland Island** (0°48′N 176°37′W) and **Jarvis Island** (0°22′S 160°03′W) all lie near the equator under the influence of both the westward-flowing SEC at the surface and the strong (1-1.5 $ms^{-1}$) eastward-flowing EUC with a core depth of approximately 50-200 m. The EUC causes localized topographic upwelling on the western side of all three islands that varies with time (e.g., El Niño/La Niña conditions). All lie within the arid zone of the equatorial Pacific with insufficient groundwater and rainfall to support continuous human habitation. Jarvis Island is a southern member of the Line Islands group and Howland and Baker Islands are northernmost members of the Phoenix Islands group and Tokelau Ridge.

The history of the PRIA are covered in a companion report (Maragos et al., 2008) and the 2005 edition of this report. Between October 2005 and April 2007, NOAA conducted biennial Pacific RAMP cruises at all seven locations, staffed by scientists from the Pacific Islands Fisheries Science Center's Coral Reef Ecosystem Division (PIFSC-CRED), the USFWS and collaborating institutions. In addition, the Scripps Institution of Oceanography (SIO) sponsored surveys at Palmyra and Kingman in August 2005, Palmyra in August 2006 and Kingman in August 2007. Since 2005, military use and occupation at Johnston Atoll has ceased, and all permanent residents were removed in 2005. TNC constructed a research station at Palmyra Atoll in 2006 that now accommodates up to 20 researchers for parts of the year. Numerous new research projects at Palmyra were proposed and initiated in 2005. In August 2006, Typhoon Ioke, the strongest storm ever reported in the Central Pacific, struck Johnston as a Category 2 hurricane and Wake as a Category 4 typhoon.

## ENVIRONMENTAL AND ANTHROPOGENIC STRESSORS

The threats and anthropogenic stressors of the PRIA prior to 2005 were discussed by Turgeon et al. (2002) and Brainard et al. (2005) in previous reports. This section updates the changes in the stressors that have been detected in the PRIA since previous surveys in 2004 and 2002.

Significant observations of environmental and anthropogenic stressors in the PRIA between 2005 and 2007 include:

- Surveys of coral disease showed a relatively low mean overall prevalence of coral disease across the region.
- Surprisingly few coral reef ecosystem impacts were apparent at Wake after Super Typhoon Ioke hit in August 2006.
- A shipwreck of a 26-m fishing vessel of unknown origin was discovered at Kingman.
- Residual metal from WWII military debris at Baker contributed to the spread of invasive cyanobacteria to adjacent reef habitats.
- Unauthorized fishing within NWR boundaries was suspected at several of the PRIA where surveillance and monitoring efforts are presently inadequate to discourage these activities.
- Alien insects were decimating the *Pisonia* beach forest at Palmyra and with non-native black rats (*Rattus rattus*) and coconut trees (*Cocos nucifera*) were thought to be limiting seabird nesting and recovery of *Pisonia* forests.
- Significant spreading of the corallimorph *Rhodactis howesii* was observed on reefs at Palmyra in 2007.

### Climate Change and Coral Bleaching

Global warming is a climate change term used to describe the overall increase in the Earth's atmospheric and oceanic temperatures over the course of the last century from increased anthropogenic greenhouse gas emissions (primarily carbon dioxide, $CO_2$) from the combustion of fossil fuels (IPCC, 2007). The rapid rate of increase in atmospheric and oceanic temperatures suggests a difference from natural climate variability. Increasing temperatures can lead to changes in sea level, weather patterns, precipitation, storm frequency and magnitude, ocean currents and local biota (IPCC, 2007). The interconnectivity of the Earth's systems suggests that changes associated with global warming will have many known and unknown cascading effects on ecosystems around the globe (IPCC, 2007).

The future effects of increasing temperatures are difficult to quantify due to the unknown and complicated nature of climatic sensitivity, environmental feedback mechanisms and greenhouse gas emissions. Anthropogenic global warming and associated sea level increases may continue for centuries due to the time scales associated with climate processes and feedbacks, even if greenhouse gas concentrations were to be stabilized (IPCC, 2007). It is predicted that coral reef ecosystems will be under great strain as a result of global warming and climate change (Hoegh-Guldberg, 1999). In addition, projections predict temperature increases and that $CO_2$ will increase beyond levels that reefs have experienced over the past half-million years (Hughes et al., 2003). Two of the major impacts from global warming on coral reef ecosystems are coral reef bleaching and ocean acidification (Kleypas, 2006).

The increase in water temperatures associated with global warming (1-2°C per century), coupled with regionally specific El Niño-Southern Oscillation (ENSO) events, appears to be the main driver of the breakdown between coral-algal symbiotic relationships (coral bleaching) in the Pacific. Reef-building corals are thought to live near their thermal maxima, making them good indicators for changing conditions, and the thermal tolerances of reef-building corals are forecast to be exceeded within the next few decades (Hoegh-Guldberg, 1999). Small increases in water temperature of 1-2°C can stress corals, causing them to expel their symbiotic algae. When these algae, which contain the photosynthetic pigments that give corals their distinct colors, are expelled from coral tissue, the coral looks white or bleached. If the corals are not able to recruit new symbiotic algae in time to fulfill their nutritional needs (which can sometimes take weeks to months), the bleaching can result in mortality of the affected coral.

A major concern is that the accelerating rate of environmental change, including increasing temperatures, could exceed the evolutionary capacity of coral and algal species to acclimate and/or adapt to these changes (Hughes et al., 1993). Bleaching events can stretch across thousands of square kilometers of ocean and immediately cause high levels of coral mortality. In addition, coral bleaching can lead to habitat phase shifts where corals are replaced by other benthic groups, along with changes to the nutrient cycling processes that are thought to be major drivers of high coral reef productivity. Recent research shows that algal-dominated areas occur naturally on many healthy Pacific reef systems (Vroom et al., 2006a). However, algal overgrowth of areas where corals have been reduced by bleaching or other factors can lead to decreased ecosystem health, decreased accumulation of calcium carbonate, and negative impacts to the reef fauna that depend on the structural complexity and food sources provided by corals.

Six major coral bleaching events have occurred since 1979, with massive coral mortality affecting reefs around the globe (Hoegh-Guldberg, 1999). The effect of bleaching events in the PRIA before surveys began in 2000 cannot be determined, and the effects of these events on the PRIA after 2000 are inconclusive. Increasing temperatures associated with global warming are likely to increase the frequency and magnitude of coral bleaching events. The proximity of some of the PRIA to the equator (Howland, Baker and Jarvis Islands) exposes them to some of the greatest changes in temperature during ENSO warming events in the Pacific, and in some cases the islands have experienced conditions that exceed predicted bleaching thresholds (Figure 11.3).

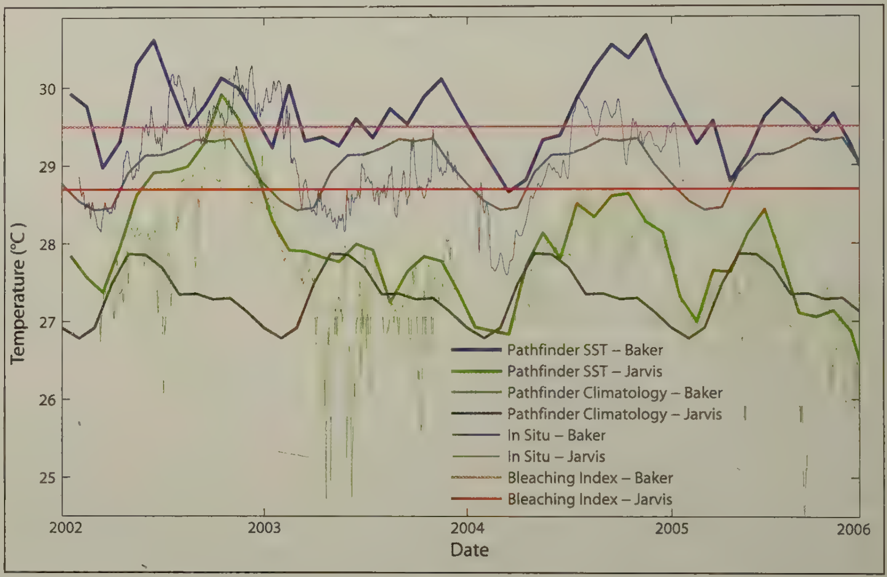


*Figure 11.3. Satellite and* in situ *temperatures at Baker and Jarvis Islands from 2002 to 2006 showing anomalously high sea surface temperatures. Both satellite Pathfinder SST (Baker – thick blue line, Jarvis – thick green line) and in situ temperatures at about 15 m depth at Baker (thin blue line) and Jarvis (thin green line) show temperature values exceeding long-term mean climatological values (Baker–light gray line, Jarvis–dark gray line). Coral Reef Watch bleaching threshold of maximum monthly mean SST plus 1°C is shown for reference. Source: Brainard et al., 2005; NODC/SOG, 2006.*

### *Calcification/Ocean Acidification*

The current and projected rates of atmospheric $CO_2$ increase, primarily from the burning of fossil fuels, are estimated at 100 times the rate that has occurred over the past 650,000 years. By the mid-21st century, it is predicted that the increased concentration of atmospheric $CO_2$ will decrease the saturation state of carbonate minerals in tropical ocean waters by 30% and biogenic-carbonate precipitation by 14 to 30% (Kleypas et al., 1999). Coral reef calcification is dependent on the saturation state of carbonate minerals in ocean waters. Reduced carbonate-saturation state promotes dissolution in reef-building corals, and decreased carbonate production makes it more difficult for marine calcifying organisms to form biogenic-carbonate minerals (Orr et al., 2005). Coral reefs are particularly threatened because reef-building organisms secrete metastable forms of carbonate minerals; however, the biogeochemical consequences for calcifying organisms in other marine ecosystems may be equally severe (Kleypas et al., 1999). In addition, the rising atmospheric $CO_2$ levels are irreversible on human timescales (Kleypas et al., 2006). Uptake of $CO_2$ by the ocean helps moderate the rising atmospheric concentrations; however, the associated and linked changes previously described in the oceanic-carbonate-chemistry system increase the concentration of hydrogen ions [$H^+$] in solution, resulting in lowered sea-surface pH and "ocean acidification".

### *El Niño-Southern Oscillation*

ENSO, resulting from the large-scale global coupling of atmospheric and oceanic circulation, is an interannual climatic phenomenon (occurring approximately every two to eight years) that creates significant temperature fluctuations in tropical Pacific Ocean surface waters. ENSO has two distinct signatures in the Pacific Ocean: El Niño and La Niña. These signatures are defined as sustained sea surface temperature (SST) anomalies of magnitude greater than 0.5°C across the central tropical Pacific Ocean (Trenberth, 1997). El Niño is associated with positive anomalies (warmer temperatures) and

La Niña with negative anomalies (colder temperatures). El Niño conditions have been linked to large-scale mortality of reef-building coral probably due to the increased temperatures and UV exposure, as well as decreased nutrients (Hoegh-Guldberg, 1999). La Niña conditions, which usually follow El Niño events, are associated with colder temperatures and increased storm activity. ENSO events can have a significant impact on coral reef ecosystems due to changing surface winds, ocean currents, water temperatures, nutrient availability, storm frequency and magnitude, etc. ENSO is a naturally occurring phenomenon; however, there is uncertainty regarding how global warming and the associated climate changes have affected the frequency and/or magnitude of this cycle and, in turn, how that will affect coral reef ecosystems.

With regard to the equatorial areas near the PRIA, ENSO has a profound impact on SST, ocean currents, winds and biological production (Philander, 1990; McPhaden et al., 1998; Figure 11.4). During an El Niño period, trade winds weaken and occasionally reverse in the equatorial Pacific, resulting in anomalously warm SST and eastward surface transport (Yu and McPhaden, 1999). These wind anomalies are typically westerly wind bursts in the Western Pacific that generate equatorial-trapped Kelvin waves propagating eastward, altering the sea surface slope and depressing the thermocline. The EUC, previously documented as the source for upwelling at Jarvis Island (Hendry and Wunsch, 1973; Roemmich, 1984; Gove et al., 2006), has been observed to weaken and, on rare occasions, reverse direction during an El Niño (Firing et al., 1983; Roemmich, 1984).

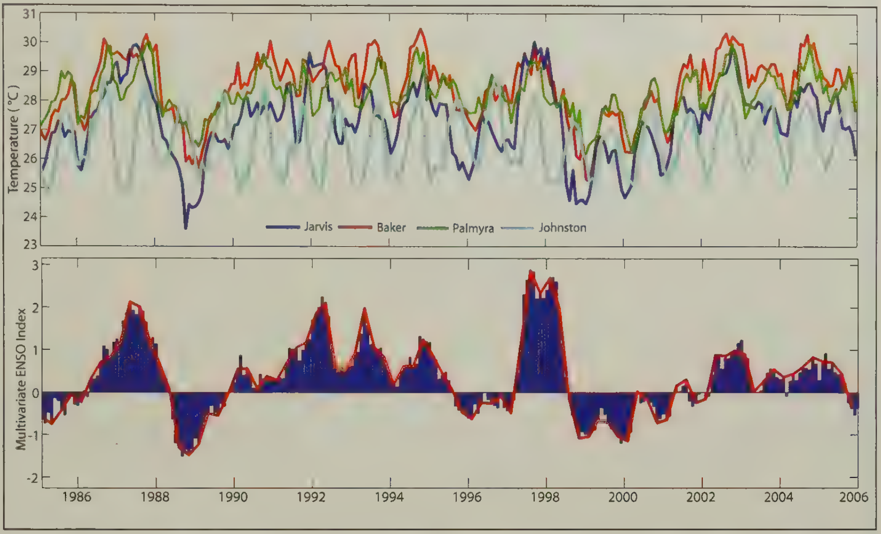


*Figure 11.4. Relationship of NOAA Pathfinder-derived SST (top) and ENSO Multivariate Index (bottom) at the PRIA. Note Jarvis' extreme dependence on ENSO contrasting with Johnston's annual cycle. Source: PIFSC-CRED, unpub. data.*

## Diseases

Because the PRIA lie beyond the influence of most human disturbance, disease surveys and monitoring in this region provide a basis against which to compare levels of disease prevalence in human impacted coral reef environments. As part of Pacific RAMP, coral disease surveys were conducted at Johnston Atoll (n=18), Howland (n=8), Baker (n=6) in 2004 and 2006; Jarvis Islands (n=9), Palmyra Atoll (n=13) and Kingman Reef (n=14) in January–March 2006; and at Wake Atoll (n=12) in April–May 2007. Rapid Ecological Assessment (REA) surveys, each covering from 200-500 m$^2$, were completed at a total of 68 discrete sites in 2006, following the methodology developed, tested and implemented in the NWHI by Greta Aeby (see Friedlander et al., 2005). Prevalence of disease at each site was computed as the percent of diseased colonies (counts) relative to the estimated total number of colonies within each survey area, as follows: P=[(total no. disease cases per site × 100) ÷ (colony density per site × total area surveyed for presence of disease per site)].

The 2006 quantitative assessments indicate that the mean overall prevalence of coral disease across the region is relatively low, affecting between 0.01 and 2.8% of colonies at each of 80 survey sites (Figure 11.5). These values are comparable to the levels reported for the NWHI. Prevalence and distribution of coral disease varied greatly both within and among coral reef locations. Of the 80 sites visited, 39 (48.8%) revealed disease, and Johnston Atoll exhibited the greatest occurrence of coral disease (78% sites) and the highest mean overall prevalence values (0.7 ± 0.2%; mean ± SE). Two shallow, western lagoon sites near Johnston Atoll exhibited overall prevalence of 2.5 and 2.8%. In contrast, low prevalence (0.1%) was detected at northern and central lagoon sites, far away from any land mass. Lesion types and prevalence values documented in 2006 are commensurate with prior quantitative coral health assessments conducted in 2004 by Aeby (Brainard et al., 2005); ob-

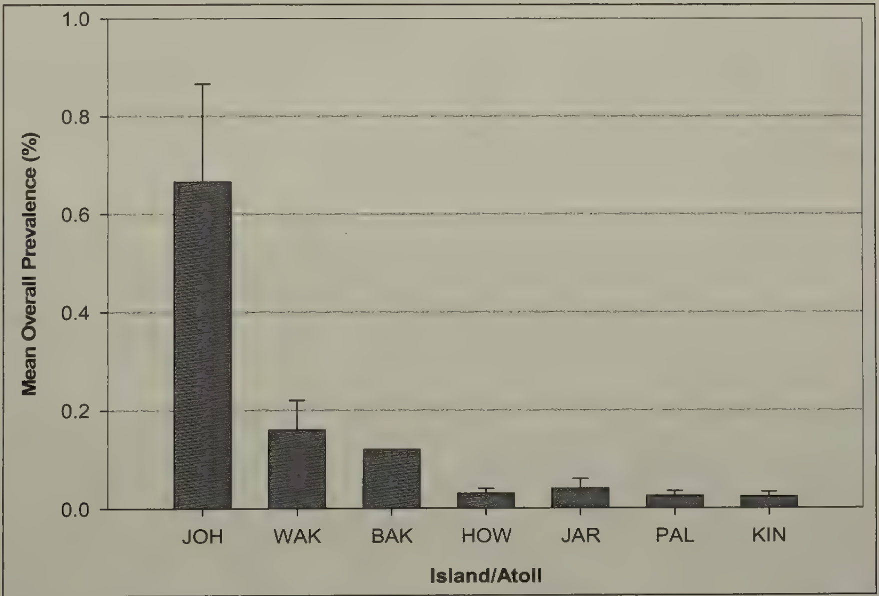


*Figure 11.5. Mean overall prevalence (%) of coral disease in the PRIA. Prevalence for each disease state was calculated relative to the total coral density (number of colonies/m$^2$) at each site surveyed. Source: PIFSC-CRED, unpub. data.*

served disease states were primarily composed of skeletal growth anomalies including "ring syndrome" (Brainard et al., 2005) and tissue loss lesions (including *Acropora* white syndrome; Figure 11.6). Skeletal growth anomalies represented 75% of the cases recorded and white syndrome/tissue loss 25%, respectively. Disease conditions were noted on three coral genera: *Montipora* (75%), *Acropora* (23%) and *Pocillopora* (2%). Of potential concern is the *Acroporid* white syndrome, which results in severe and rapid tissue loss on the tabular *Acropora cytherea* (Willis et al., 2004; Bythell et al., 2004). Based on ecological monitoring at 12 permanent stations, stands of *A. cytherea* at Johnston Atoll have suffered approximately 50% population reduction between 2004 and 2006. Thus, continued monitoring of this disease and its host species are needed. More detailed information on coral disease appears in the Benthic Habitats section of this chapter.

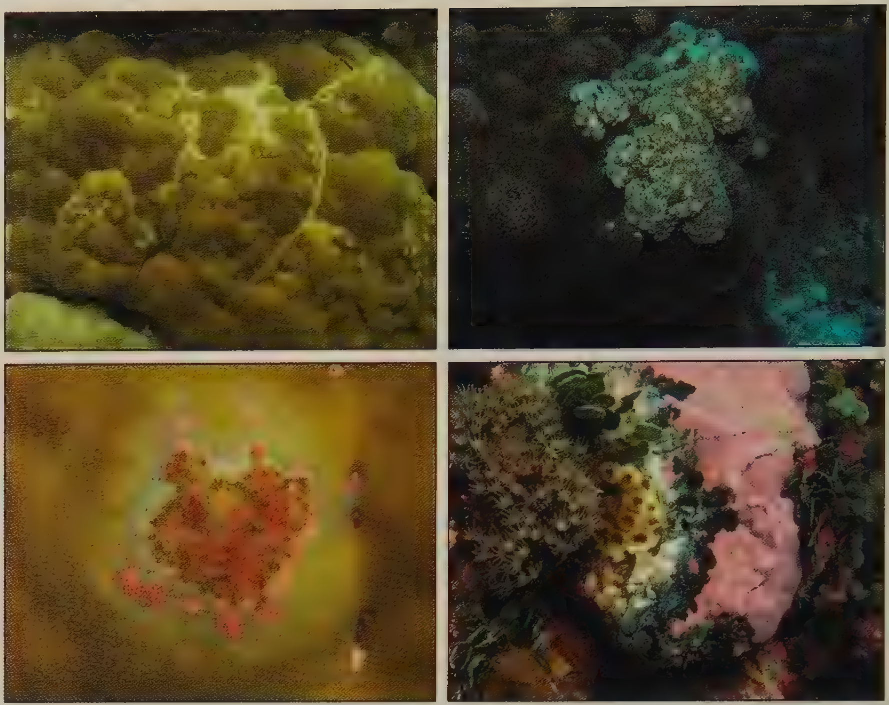


*Figure 11.6. Underwater photographs illustrating the field appearance of lesions affecting scleractinian corals and coralline algae in the U.S. PRIA 2006; from top left, clock-wise:* Porites *growth anomaly;* Montipora *growth anomaly;* Porites *tissue loss and pigmentation response; and black fungal disease of crustose coralline algae. Photos: Bernardo Vargas-Ángel, PIFSC-CRED.*

No prior records of coral disease occurrence are available for Wake Atoll because no disease surveys were conducted prior to PIFSC-CRED's Wake-Marianas Pacific RAMP cruise in April-May of 2007. During the surveys, mean overall disease prevalence at Wake Atoll was found to be low (0.16 ± 0.06; Figure 11.7) with skeletal growth anomalies being the most abundant disease state (73% of cases), followed by other lesions and white syndrome/tissue loss (16 and 11%, respectively). Disease conditions affected six different coral genera, with *Porites* exhibiting 50% of cases, followed by *Goniastrea* (21%), *Montipora* (8%), *Acropora* (8%) and *Astreopora* (8%).

Disease prevalence was notably low at Howland and Baker (0.01%, 0.03 ± 0.02%, respectively), with skeletal growth anomalies on staghorn *Acropora nobilis* being the only type of lesion observed. Additionally, a few colonies were affected by tube-worm infestations. For Palmyra Atoll and Kingman Reef, occurrence of disease was low, comparable to Howland and Baker Islands. Disease states enumerated at Palmyra Atoll included skeletal growth anomalies (32%), other lesions (68%) such as pigmentation responses and discoloration, and tube-worm infestations. Disease was documented at 54% of survey sites visited, and mean prevalence amounted to 0.05 ± 0.01% (range 0.02–0.1%). The coral genera affected included, in descending order: *Porites* (68%), *Acropora*, *Pocillopora* (10.5% each), and *Favites* and *Hydnophora* (5.5% each). Three main disease states, skeletal growth anomalies (60%), tissue loss (5%), and other lesions (35%), were visible at 6 of the 14 sites visited (43%) at Kingman Reef. In descending order of importance, diseases affected corals in the following genera: *Porites* (75%), *Acropora* and *Pocillopora* (10% each), and *Herpolitha* (5%). Mean disease prevalence for Kingman was lower than for Palmyra (0.02 ± 0.01%; range 0.01–0.04%).

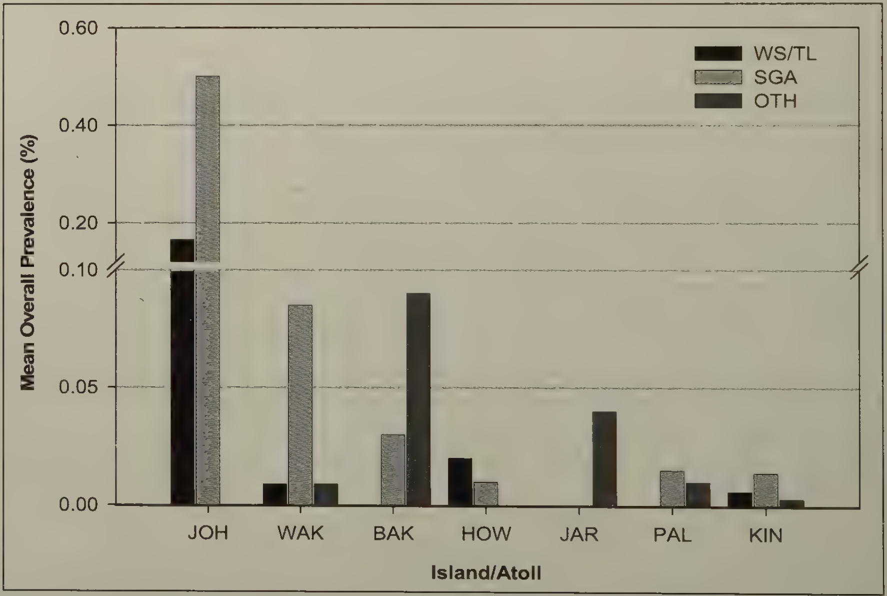


*Figure 11.7. Mean overall prevalence of white syndrome (WS/TL), skeletal growth anomalies (SGA), and "other lesions" (OTH) including unusual discolorations, irritations and pigmentation responses, tube-worm infestations and unidentified lesions causing deterioration of coral condition in the U.S. PRIA. Prevalence for each disease state was calculated relative to the total coral density (no. colonies/m$^2$) at each site surveyed. Source: PIFSC-CRED, unpub. data.*

The 2006 surveys revealed diseases for algae as well. Cases of a black fungal disease affecting crustose coralline algae (Littler and Littler, 1998) were encountered at Palmyra and Kingman. Although present in relatively low abundances (1.0 ± 0.38 case/100 m$^2$; range 0.5–7.5 cases/100 m$^2$), these observations expand the geographical range of the black fungal coralline algal disease, which until now was only known from American Samoa (Littler and Littler, 2003).

## Tropical Storms/Wave Action

In general, the PRIA of Johnston, Kingman, Palmyra, Jarvis, Howland and Baker experience low frequencies of tropical storm events. These islands and atolls are located in between the major eastern and western Pacific tropical storm centers, which are most active in late summer and early fall. Most storms that develop off the coast of Mexico and head west undergo cyclolysis (storm death) or spin off northwards before reaching the longitude of the PRIA.

In late August and early September 2006, Hurricane/Typhoon Ioke (Figure 11.8 and 11.9), one of the strongest storms ever recorded in the Central Pacific, struck the two northernmost islands of the PRIA. Ioke passed over Johnston Atoll as a Category 2 hurricane and over Wake Atoll as a Category 4 typhoon. Wake Island, completely evacuated of all 188 residents due to Ioke's projected path, sustained winds of over 320 km per hour, driving a storm surge over the island and forcing powerful waves into the lagoon (Figure 11.10). Large concrete cubes filled with coral rubble and sand used to build a seawall on the eastern side of the island were dislodged and thrown tens of meters up the beach (Figure 11.11). In addition, some of the WWII-era concrete bunkers on the beach were overturned.

According to PIFSC-CRED interviews of a Wake resident in 2007 (S. Sweistac, pers. comm.) the concrete, coral/concrete and cinder block structures, mostly built during WWII, fared much better than more recent buildings that were constructed of weaker materials. Numerous buildings were entirely destroyed and roof damage was extensive; recovery operations were still underway eight months after the storm. Fortunately, two large tanks containing aviation fuel survived the storm intact, but a third empty tank sustained considerable damage. Australian ironwood (*Casuarina)* trees on the island were denuded by the storm, but had made a significant come-back over the following eight months.

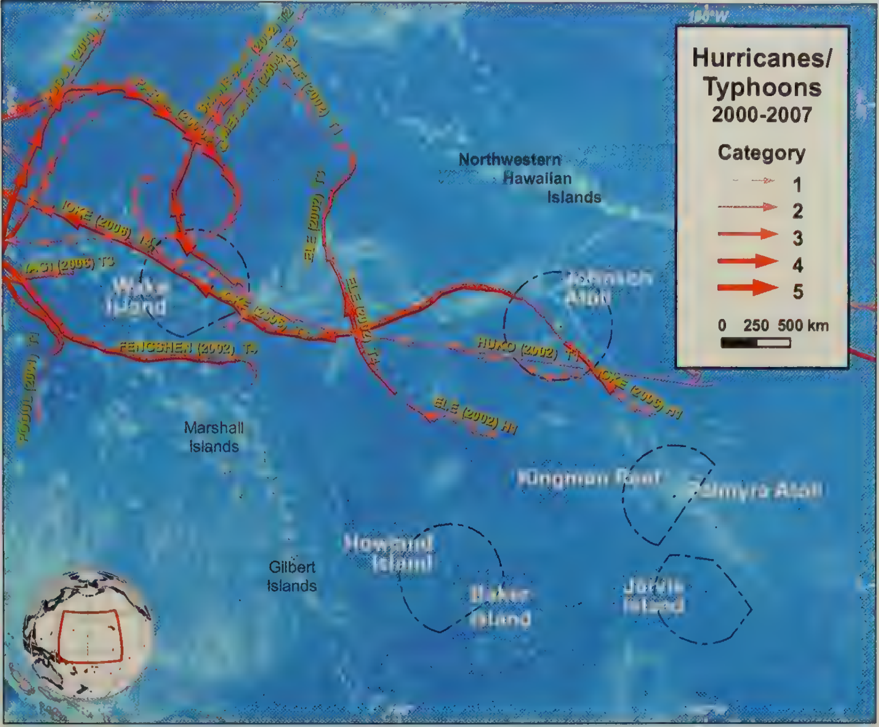


Figure 11.8. A map showing the path, name, year and intensity of tropical storms passing near the PRIA from 2000-2007. Map: K. Buja. Source: http://weather.unisys.com/hurricane/.

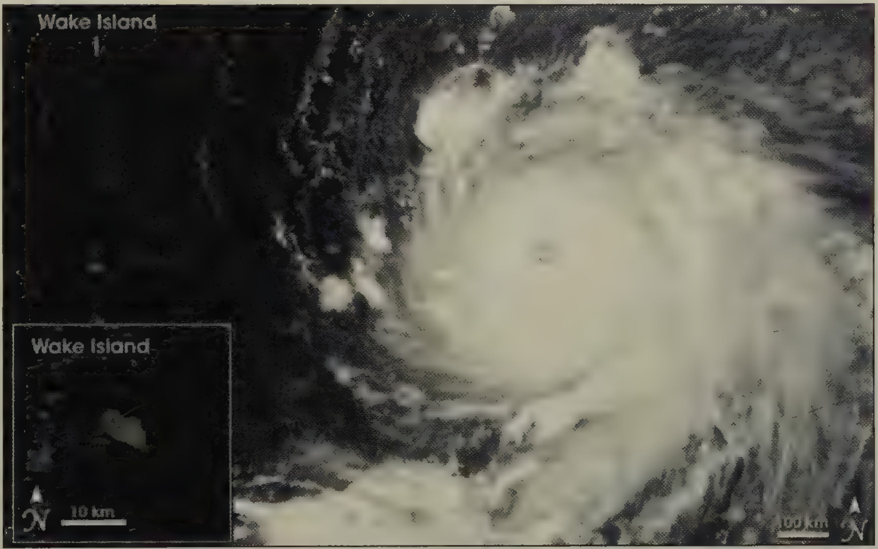


Figure 11.9. Super Typhoon Ioke, August 31, 2006. Source: NASA Earth Observatory.

## Coastal Development and Runoff

Most of the PRIA are uninhabited and have experienced few contemporary impacts from coastal development and runoff. However, there are residual impacts from military occupation and use of Johnston, Palmyra and Wake Atolls. Ship channels were dredged into the lagoons of all three, and defensive perimeter land areas were constructed around Palmyra and Wake. During WWII, Palmyra was attacked by Japanese aircraft, and Wake was taken and occupied by Japanese forces for the duration of the war. The military dredging and filling operations drastically changed water circulation patterns that still affect marine life at all three atolls.

After WWII, military use of Johnston Atoll included high-atmospheric nuclear weapons testing, chemical munitions storage and their destruction via incineration and radioactive waste cleanup after two failed Thor launches. A 25-acre landfill

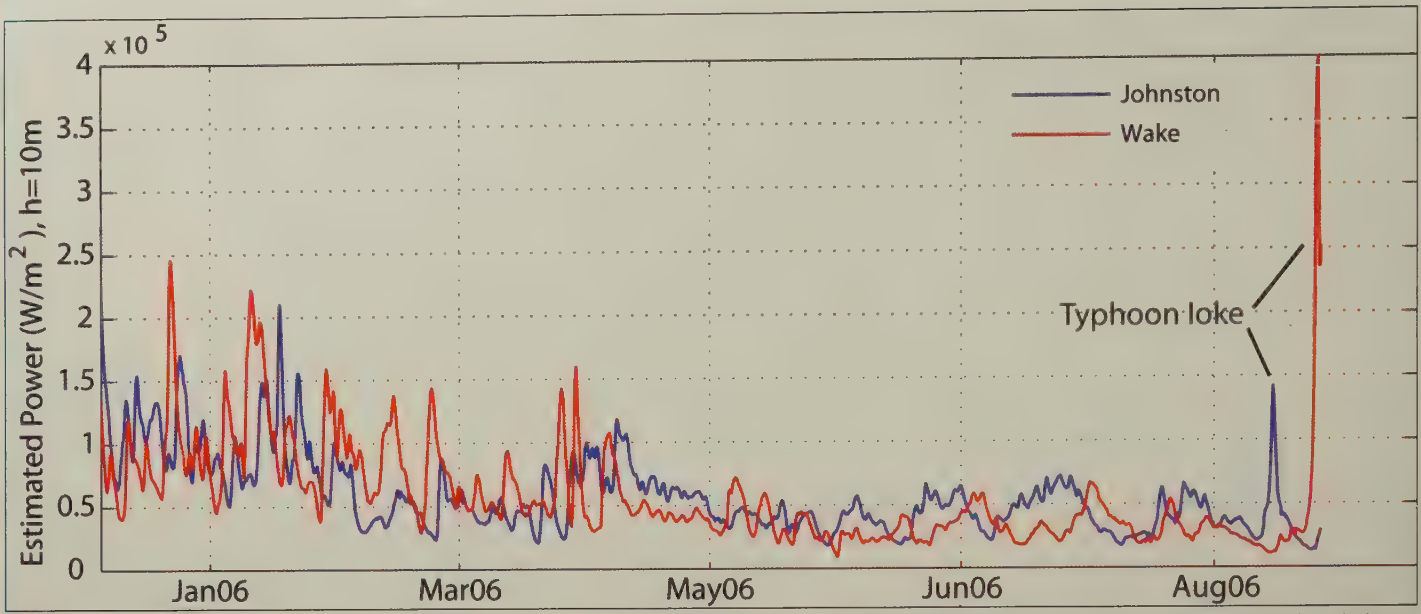


*Figure 11.10. Modeled wave heights for January to mid-August 2006 from Johnson Atoll and Wake Atoll showing the anomalously large wave power associated with Hurricane/Super Typhoon Ioke. Source: PIFSC-CRED, unpub. data.*

on Johnston Island still contains radioactive plutonium debris and soils. Johnston Atoll was deactivated by the military in 2005, and all personnel and structures, except one building, were removed from the island. At present, the U.S. Air Force is planning to relinquish the atoll, and the USFWS is likely to acquire the entire atoll and expand the NWR boundaries beyond those that were established by Presidential Executive Order in 1926.

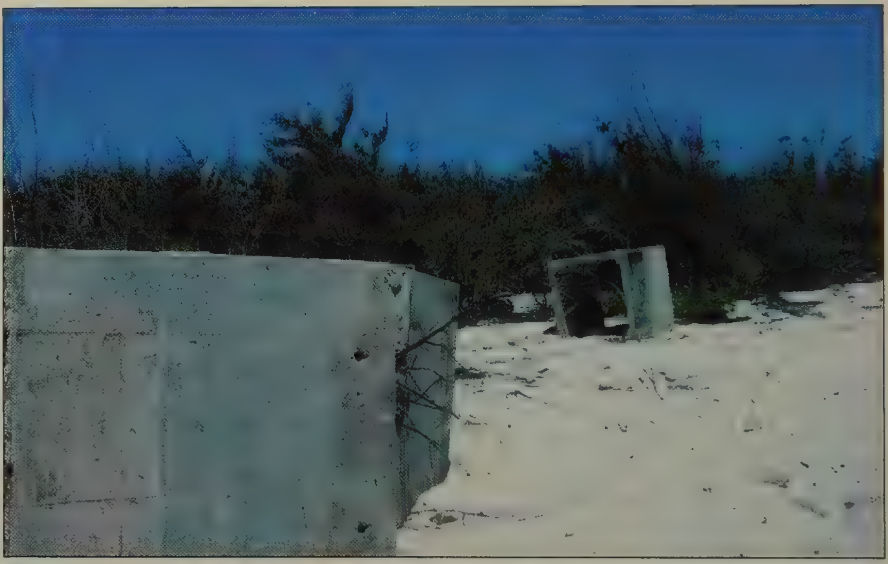


*Figure 11.11 Concrete blocks filled with sand and coral rubble to form a seawall were carried tens of meters up the beach on Wake Island. Photo: J. Miller.*

In 2000, Palmyra was purchased by TNC, and in 2001 the USFWS purchased all of Palmyra from TNC except for the main island (Cooper) and established the Palmyra Atoll NWR. In 2006, TNC completed construction of a research station at Cooper Island. The station's research agenda includes lagoon restoration, climate change, shifting baselines for healthy coral reefs, invasive species and other global environmental threats with the goal of discovering and developing new conservation strategies for island habitats throughout the Pacific and the world. The USFWS oversees conservation management and research at the atoll in cooperation with TNC, which manages the research station and related activities on Cooper Island. Members of the research consortium include Stanford University, SIO, American Museum of Natural History, California Academy of Sciences, University of California at Santa Barbara and at Irvine, University of Hawaii, U.S. Geological Survey, TNC and Victoria University of Wellington, New Zealand. Funded by the Gordon and Betty Moore Foundation and built at a cost of $1.5 million, the station offers accommodations for up to 20 researchers, including a new galley, guest cabins, flush toilets, shower house, boat shed, a water catchment and treatment system to generate 100,000 gallons of potable water, environmentally-friendly sewage treatment, electrical generators, a maintenance shop, research laboratory, and TNC and USFWS offices. A satellite-based Internet and communications system was also installed.

Wake Atoll continues to be inhabited by military and contracting personnel. Operations buildings and residences have been largely repaired and the runway is in excellent condition. No other construction is currently planned.

## Coastal Pollution

No coastal pollution was reported in the PRIA during this time period. However, researchers noted sedimentation and resultant stress on the corals located on a reef south of Johnston Island in 2006. The source and cause of the sedimentation was not determined.

## Tourism and Recreation

TNC and USFWS employees deployed to Palmyra NWR to manage the research station and refuge participate in recreational activities for an average of 0.5-0.75 days per person per week. Detailed logs of recreational activities in the refuge (snorkeling, diving, swimming, boating, sport fishing, kayaking, wildlife observation and photography) are maintained by USFWS. Palmyra has historically been a popular stopover for yachts sailing in the central Pacific because of safe anchorage and plentiful freshwater. Yachts are still permitted by the NWR to visit Palmyra, but are limited to seven-day stays. In 2006, nine recreational yachts visited the Palmyra Atoll NWR in five months. Six of these vessels pre-arranged their visits, and three were unannounced. The average number of passengers and crew aboard was three per vessel and the average stay was five days per vessel. During this five-month period, a total of 165 visitor-use days were recorded on the refuge from visiting yachts. Visiting yachters also participated in recreational activities

Wake Atoll is a closed facility and not subject to visits from recreational yachts or tourists. There is a 14-hole (un-watered) golf course on the island for use by the resident population, which also has access to two small sport fishing vessels and a number of kayaks at the facility's recreational beach. There is also a small recreational diving club on the island.

## Fishing

Commercial fishing is prohibited by law within the boundaries of NWRs. Baker, Howland and Jarvis have 3-nm boundaries that extend seaward from the territorial baselines (island shorelines). Twelve nm boundaries were established for Kingman, Palmyra and Midway after President Reagan extended U.S. territorial seas from 3 to 12 nm via Presidential Executive Order in 1986. However, as reported in the 2005 PRIA chapter, it is suspected that occasional incursions by commercial fishing vessels occur; little monitoring activity is possible in these remote areas, but evidence of commercial fishing incursions, such as the grounding of fishing vessels at Palmyra (1991), Rose (1993) and Kingman (2007) is apparent.

The USFWS monitors inshore vessel activity within the Palmyra Atoll Refuge, but limited access to offshore vessels prevents monitoring offshore. When visiting the atoll, yachts sometimes report the presence of commercial fishing vessels. Using radios, it is sometimes possible to determine whether a vessel is fishing within the 12-nm NWR limit or simply transiting the waters. In some cases, lights from fishing vessels can be seen at night from Palmyra, but contact via radio may or may not be possible.

At Palmyra Atoll, limited offshore blue-water fishing is allowed for subsistence purposes. No fish or coolers of fish are allowed to be taken off island by plane or ship. The fishing occurs primarily on the southern and western sides of the atoll, and yellowfin tuna (*Thunnus albacares*) and wahoo (*Acanthocybium solandri*) are the most commonly caught species. As an example of typical fishing activity, between May and September 2006, 28 tuna (weighing between 4.5 and 28 kg) and eight wahoo (weighing between 8.6 and 15 kg) were caught during 17 fishing trips. Non-target species, primarily grey reef sharks, are caught as bycatch, but are dehooked and released whenever possible. In the same period, 13 grey reef sharks were landed, 10 of which were released. Bonefish (*Albula vulpes*) fishing and catch-and-release fishing are also allowed at Palmyra for recreational purposes, but no such activities were recorded between May and September 2006. At Wake Atoll, the residents currently use two small fishing boats for subsistence and recreational fishing. Wahoo is the most commonly caught pelagic fish. Stuffed trophies of large tuna and marlin that have been caught around the island are displayed in the operations office.

## Trade in Live Coral and Live Reef Species

There is no documented trade in live coral or reef species in the PRIA.

## Ships, Boats and Groundings

### *Baker Island*

The anchorage off the western leeward side of the island was used by guano miners during the late 19th century and by U.S. forces during the WWII era. Coral surveys during 2000-2006 near the site reveal increased levels of cyanobacteria and corallimorphs that appear to be stimulated by dissolved iron from discarded metallic debris. A dive survey to a depth of 35 m off the anchorage in 2006 revealed numerous corroding anchors and chains, but no vessels or other bulky military material. Upwelling waters may be transporting dissolved iron and other chemicals up the western slope from greater depths. In addition, large sections of anchor chain and ground tackle were noted during towed-diver surveys along the western reef slope. Coral populations monitored at the permanent REA monitoring site off the island landing appear to be gradually declining and the corallimorph *Rhodactis howesii* increasing. More detail on coral populations appears in the Benthic Habitats section of this chapter.

### *Johnston Atoll*

A barge wreck site was identified at Johnston Atoll using multibeam sonar in 2006; divers also examined the wreck. In the area of the wreck, significant changes in the coral assemblage were determined based on a high abundance of the corallimorph *Rhodactis howesii*.

### Palmyra Atoll

A Japanese longline fishing vessel that wrecked at Palmyra in 1991 was corroding badly in 2006, resulting in the rapid spread of *Rhodactis howesii*. The corallimorph was smothering corals and algae up to 100 m downcurrent of the wreck in 2006 and has now spread to areas over 2 km away from the wreck site.

### Kingman Reef

The grounding of a wooden 26-m fishing boat at Kingman was investigated during the USFWS and SIO expedition in August-September 2007. The hull was still intact, and the impacts are presently limited to cyanobacteria outbreaks within 20 m of the wreck. It is not yet known whether the ship still contains fuel. The cumulative impacts to the reef would be much greater if the ship breaks up before being removed from the reef. At present, the U.S. Coast Guard is taking the lead in further action regarding the wreck.

### Wake Atoll

Wake was the site of a furious WWII battle in 1941, and there are numerous wrecks around the atoll, on beaches, in shallow waters and in deeper waters. NOAA towed-diver surveys noted the presence of eight large anchors and associated ground tackle west of the harbor entrance in waters between 15-20 m deep. In addition, towed-diver surveys noted a large cyanobacteria bloom near a shallow wreck (R/C *Stoner*) on the eastern side of the harbor entrance in 2007, which was not readily apparent during surveys completed in the same area in 2005. The locations of deeper wrecks are not well documented, but one possible wreck approximately 200 m in length was identified from the 2007 multibeam surveys on the eastern side of the island in water depths between 430 and 460 m.

## Marine Debris

Marine debris in the PRIA occurs primarily in the form of WWII-era debris and is discussed above. No attempts to characterize other sources of marine debris in the islands have been undertaken.

## Security Training Activities

Naval Defensive Sea boundaries established by Presidential Executive Order prior to WWII remain in effect out to 3 nm for all of the PRIA covered in this chapter. Military vessels or military-contract vessels are occasionally seen near Palmyra Atoll. When possible, contact is made with the vessels to determine the nature of the activities. For example, on June 11, 2006, an unknown vessel was sighted and contacted by the TNC and USFWS managers. It was determined to be the Sumner, a U.S. Navy contract vessel performing bathymetric surveys. TNC and USFWS managers informed the vessel that the protected boundaries of the NWRs extend 12 nm around Palmyra and Kingman Reef. At Wake Atoll, security training activities are conducted regularly.

## Offshore Oil and Gas Exploration

No offshore oil and gas exploration currently occurs in the PRIA.

## Other

### Crown-of-thorns Sea Star (Acanthaster planci)

In 2006, monitoring for evidence and impacts of crown-of-thorns sea star (COTS) predation indicated the presence of scars and active feeding, particularly at Johnston Atoll and Kingman Reef (Figure 11.12). COTS predation was verified at 30% of REA sites surveyed at Johnston, particularly at exposed fore reef habitats. At Kingman, feeding was documented to be most prevalent in back reef and patch reefs locales. Sites KIN-8 and KIN-3 in the north and southeast lagoon revealed as many as 44 and 29 feeding scars, respectively, in an area of approximately 500 m$^2$ each. Feeding scars and active feeding at Kingman Reef most commonly occurred on colonies of *Porites*, but also on *Astreopora*, *Acropora*, *Montipora*, *Pocillopora*, and occasionally on *Favia* and *Fungia*.

The presence of snail (*Drupella*) predation on corals was also noted at Baker Island, Palmyra Atoll, and Kingman Reef (Figure 11.12). At Baker, *Drupella* feeding activity was concentrated on the staghorn *Acropora nobilis*, with all eight sites visited exhibiting snail infestation and predation scars. At Palmyra and Kingman, snail corallivory occurred mainly on *Pocillopora*, but also on massive *Porties* and laminar *Montipora* (PIFSC-CRED, unpub. data).

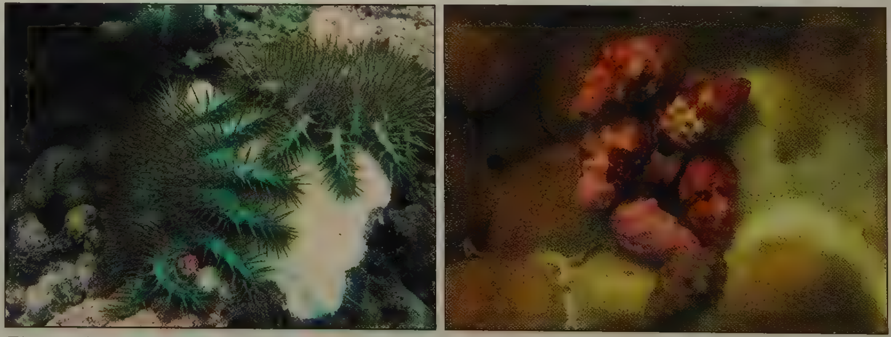


*Figure 11.12. COTS on colonies of* Porites sp *at Kingman reef (left) and active feeding and feeding scars of corallivorous* Drupella *(right). Photos: B. Vargas-Ángel.*

## CORAL REEF ECOSYSTEMS—DATA-GATHERING ACTIVITIES AND RESOURCE CONDITION

Biota and habitat monitoring, data collection and analyses, and summaries of published studies concentrate on three functional and structural components of coral reef ecosystems: marine water quality and oceanographic conditions, benthic habitats and coral reef-associated fauna (Table 11.1). Methods described in the 2005 report are listed, with a brief discussion of changes or new protocols added since 2005. An assessment of the overall condition of each ecosystem component is also presented. Monitoring sites are depicted in Figure 11.13.

*Table 11.1. Research Programs in the Pacific Remote Island Areas. Source: J. Miller and J. Maragos.*

| PROGRAM | OBJECTIVES | FIRST YEAR | FUNDING | AGENCIES |
|---|---|---|---|---|
| Bird Monitoring | Nesting seabirds and migratory shorebirds | 1985 | DOI | USFWS |
| Oceanographic Monitoring | Water chemistry and carbonate production | 2000 | NOAA | PIFSC-CRED |
| | Circulation patterns and water movement | 2006 | NOAA | PIFSC-CRED |
| | Tide and temperature monitoring | 2006 | SEA | SEA |
| | Educational oceanography | 2006 | TNC/FWS | PARC |
| Coral Monitoring | Permanent coral/clam monitoring sites | 2000 | DOI | FWS |
| | Microbial and coral diversity | 2006 | NOAA | PIFSC-CRED |
| | Benthic dynamics and coral recovery | 2006 | TNC/FWS | PARC |
| Habitat Mapping | Produce moderate-depth habitat map | 2001 | NOAA | PIFSC-CRED |
| | Algae monitoring | 2003 | NOAA | PIFSC-CRED |
| Marine Mammal and Reptile Monitoring | Monitor and assess populations | 2006 | NOAA | PIFSC |
| | Sea turtle assessments | 2006 | TNC/FWS | FWS/PARC |
| Fisheries Monitoring | Fisheries stock assessment and monitoring | 1950 | NOAA | PIFSC |
| | Reef fish monitoring | 2000 | NOAA | PIFSC-CRED |
| | Blacktip shark monitoring | 2006 | TNC/FWS | PARC |
| | Dynamics of larval fish | 2006 | TNC/FWS | PARC |
| | Compare fish populations | 2006 | TNC/FWS | PARC |
| | Apex predators and reef ecosystem effects | 2006 | TNC/FWS | PARC |
| | Production and energy flow of fishes | 2007 | TNC/FWS | PARC |
| | Mullet and gobi diversity | 2006 | TNC/FWS | PARC |
| | Bonefish diversity and post-release stress | 2006 | TNC/FWS | PARC |
| Other Biological Studies | Opisthobranch mollusk recovery | 2006 | TNC/FWS | PARC |
| | Octopus and stomatopod diversity | 2006 | TNC/FWS | PARC |
| | Bottom dwelling diversity | 2006 | TNC/FWS | PARC |
| | Barnacle diversity | 2006 | TNC/FWS | PARC |
| | Polychaete diversity | 2006 | TNC/FWS | PARC |
| | Echinoderm diversity | 2006 | TNC/FWS | PARC |
| Geological Studies | Palmyra lagoon changes due to WWII | 2006 | TNC/FWS | PARC |

PARC = The Palmyra Atoll Research Consortium
SEA = Sea Education Association

Since 2000, NOAA PIFSC-CRED and the USFWS have sponsored biennial cruises to monitor the ecosystems of the PRIA. Except at Palmyra and Wake, virtually all monitoring and assessment activities conducted in the PRIA have been done by scientists from the USFWS and PIFSC-CRED, working in collaboration with the University of Hawaii's Joint Institute for Marine and Atmospheric Research. Cruise reports for 2005-2007 with appendices that include preliminary data analyses can be accessed at http://www.pifsc.noaa.gov/library/cruise.php (Timmers et al., 2006; Vroom et al., 2006b; Schroeder et al., 2006; Ferguson et al., 2006; Ferguson et al., 2007). Protocols used in the PRIA are similar or identical to those used during Pacific RAMP surveys of U.S. jurisdictions throughout the Pacific, allowing direct comparison of results that have been obtained using the same methods and, in many cases, by the same scientists.

The Palmyra Atoll Research Consortium has initiated a variety of ecosystem research projects at the recently established Palmyra research facility. In particular, SIO conducted detailed ecological surveys at the five northern Line Islands in August-September 2005, including Palmyra and Kingman, and followed up with additional surveys at Palmyra in 2006. In August and September 2007, SIO sponsored another expedition to Kingman involving microbe, coral, fish and algal surveys at multiple depths (5 m, 10 m, 20 m) at 15 fore reef sites and at more than 50 sites in other major habitats (back reef, pinnacle, reef pool).

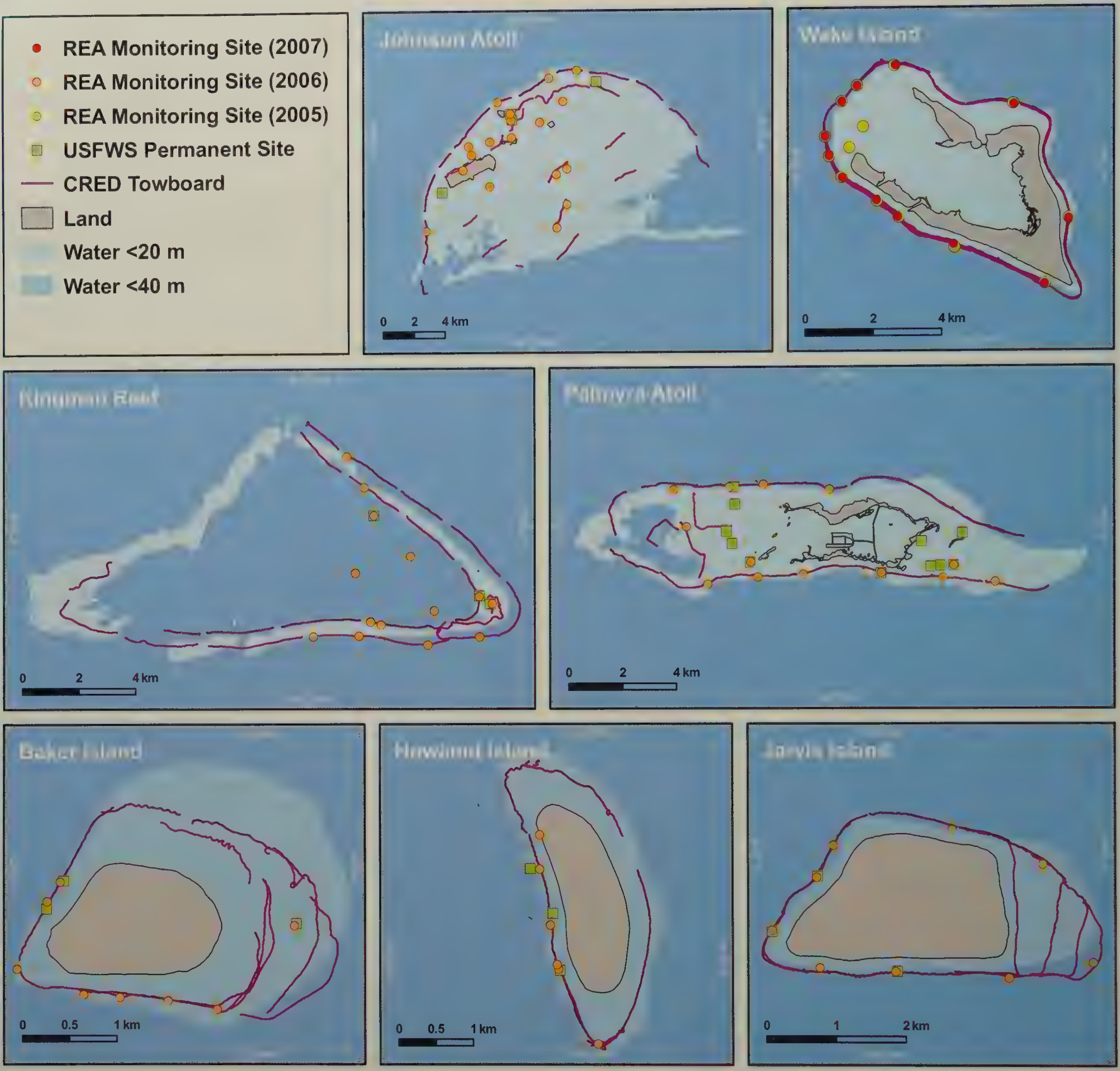

● REA Monitoring Site (2007)
● REA Monitoring Site (2006)
● REA Monitoring Site (2005)
▨ USFWS Permanent Site
CRED Towboard
Land
Water <20 m
Water <40 m
Johnson Atoll
0 2 4 km
Wake Island
0 2 4 km
Kingman Reef
0 2 4 km
Palmyra Atoll
0 2 4 km
Baker Island
0 0.5 1 km
Howland Island
0 0.5 1 km
Jarvis Island
0 1 2 km

*Figure 11.13. Map of monitoring locations discussed in this chapter. Map: K. Buja.*

## WATER QUALITY AND OCEANOGRAPHIC CONDITIONS

The health, functioning and biogeography of the PRIA coral reef ecosystems are influenced by the regional oceanographic conditions. The broad and diverse biological communities that make up these ecosystems (fish, corals and other invertebrates, algae, turtles and marine mammals) are subject to fluctuations of time-varying ocean currents, waves, temperature, salinity, turbidity, nutrients and other measures of water quality and oceanographic conditions. As these conditions change over time, so do the physical condition, distribution, abundance and species diversity of coral reef communities. Table 11.2 presents long-term oceanographic monitoring methods and equipment used in the PRIA since 1999.

Palmyra Atoll lies approximately 5.5° north of the equator in the ITCZ where the northeast and southeast trade winds meet. The prevailing wind climate is light and variable, and is punctuated by periods of northeasterly winds (Figure 11.14). Palmyra Atoll experiences periodic fast-moving squalls, which generally proceed from east to west and are associated with heavy rainfall.

*Table 11.2. Oceanographic monitoring systems in the PRIA. Source: PIFSC-CRED.*

| SYSTEM | VARIABLES MONITORED | DATES | AGENCY |
|---|---|---|---|
| Deep-water CTDs* at select locations near the islands | Conductivity (salinity), temperature, depth, dissolved oxygen, chlorophyll to a depth of 500 m | February 1999-Present | PIFSC-CRED |
| Shallow-water CTDs - multiple sites each island/atoll | Temperature, salinity, turbidity | February 2001-Present | PIFSC-CRED |
| Water Samples | Chlorophyll and nutrients (nitrate, nitrite, silicate, phosphate) concurrent with deep and shallow-water CTDs at select depths | July 2003-Present | PIFSC-CRED |
| Coral Reef Early Warning Buoys - 1 enhanced (Palmyra) | Enhanced: Temperature (1 m), conductivity (salinity), wind, atmospheric pressure, ultraviolet radiation, photosynthetically available radiation | February 2002-Present | PIFSC-CRED |
| Sea Surface Temperature (SST) Buoys - 6 (Johnston, Kingman, Wake, Jarvis, Baker, Palmyra) | Temperature at 0.5 m | February 2002-Present | PIFSC-CRED |
| Subsurface Temperature Recorders - 44 (all islands) | Temperature at depths between 0.5 and 30 m | February 2002-Present | PIFSC-CRED |
| Ocean Data Platforms (ODP) - 2 (Baker, Jarvis) | Temperature, conductivity (salinity), spectral waves, current profiles | October 2002-Present | PIFSC-CRED |
| Wave and Tide Recorders (WTR) - 1 (Johnston) | Wave and tidal heights | July 2003-Present | PIFSC-CRED |

CTD*= Conductivity, temperature and depth.

The physical interaction of ocean currents around Jarvis Island has been the focus of two historical oceanographic surveys, which showed that the blocking of the EUC by Jarvis results in current-flow stagnation and shallowing of isotherms on the upstream or western side of the island (Hendry and Wunsch, 1973; Roemmich, 1984). More recently, a study by Gove et al. (2006) focused on the time dependency of nearshore temperature fluctuations, and showed that upwelling at Jarvis can be highly variable on seasonal-to-interannual time scales. The superposition of internal tides on EUC-driven upwelling can produce rather remarkable temperature changes, some as great as 4°C and occurring multiple times a day (Figure 11.15).

Variable upwelling can provide a significant source of nutrients to the surrounding ecosystem, helping to fuel productivity to an otherwise oligotrophic environment. Water quality samples recently collected from Jarvis showed a marked increase in nutrient and chlorophyll concentrations in upwelled waters, and in some cases, showed three to four times greater concentrations compared to samples collected at other locations around the island (Figure 11.16).

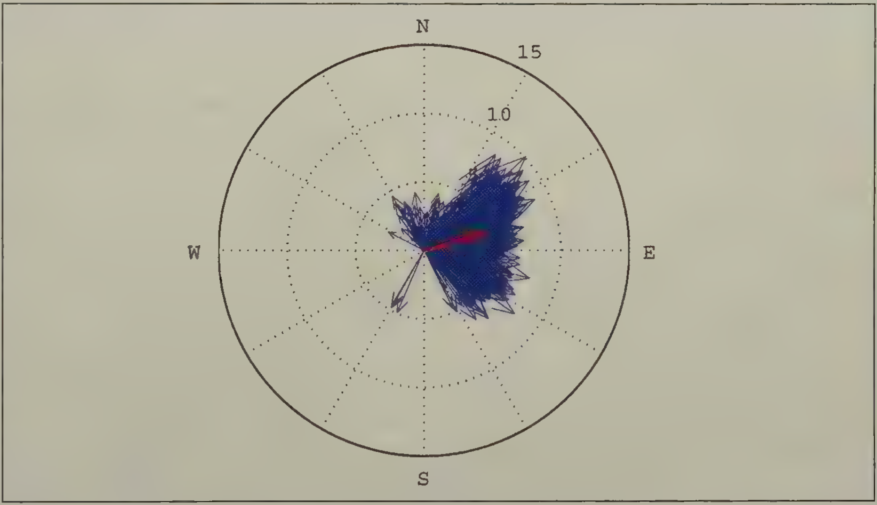


*Figure 11.14. Wind plot for Coral Reef Early Warning System buoy data 2 m above the sea surface at Palmyra Atoll. Blue arrows depict the daily averaged wind direction and magnitude (from 0–15 m/s) for the time period from March 30, 2004–April 12, 2006 and the red arrow is the average wind direction and magnitude for that entire time period. Data points outside of three standard deviations from the mean were removed prior to plotting. Source: PIFSC-CRED, unpub. data.*

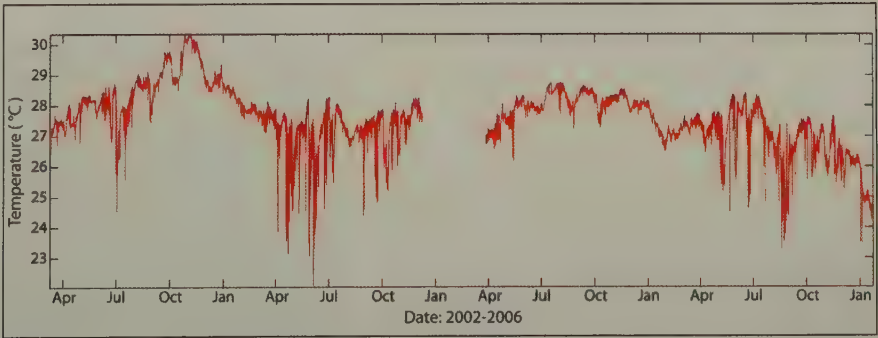


*Figure 11.15.* In situ *temperature at approximately 15 m depth from the west side of Jarvis Island shows variable upwelling superposed with periods of high frequency temperature fluctuations of 1–4 °C occurring one/two times daily. Source: Gove et al., 2006.*

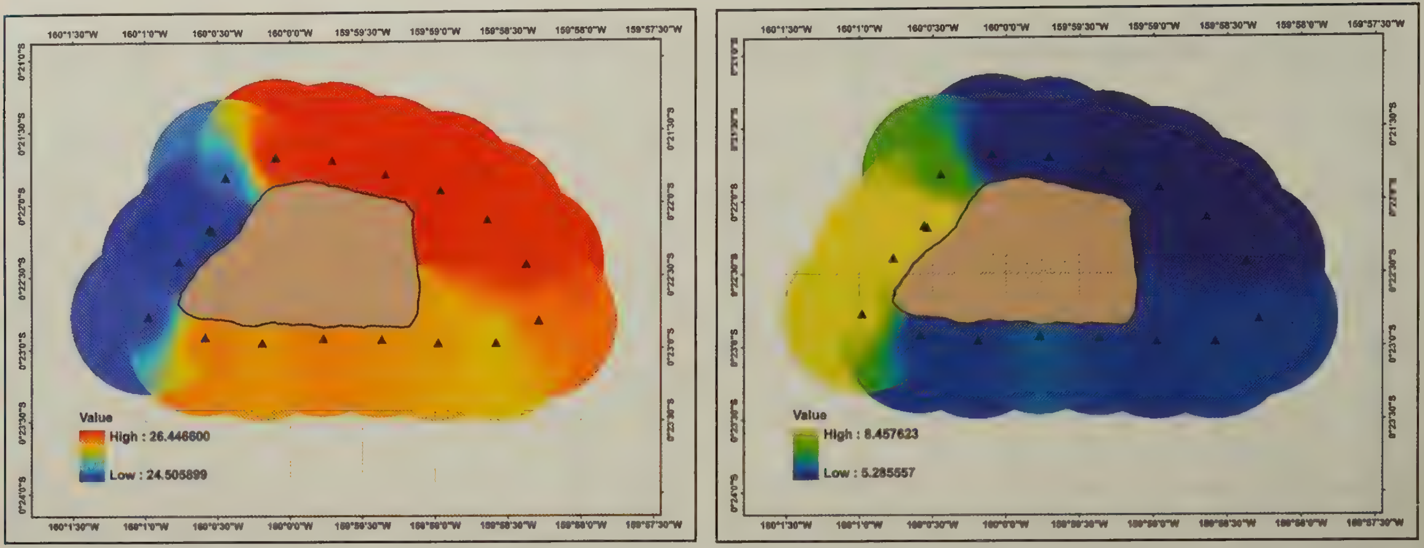


*Figure 11.16. The left panel depicts Jarvis Island water temperature at 30-m depth showing the upwelling of cooler, nutrient-rich waters originating from the EUC near Jarvis Island. Upwelled waters influence fish assemblages and distributions and other components of the local coral reef ecosystem. The right panel depicts Jarvis Island total nitrogen concentration at 30-m depth illustrating nutrient enrichment following upwelling patterns. The black triangles in both plots indicate* in situ *sampling sites for temperature and nutrients. Source: Gove et al., 2006.*

## BENTHIC HABITATS

The PIFSC-CRED Pacific RAMP conducts biennial cruises to understand benthic community structure at all PRIA and to monitor the health of the coral and algae habitats over time. The Pacific-wide scope of this monitoring program, using similar protocols in the Hawaiian Archipelago, the Mariana Archipelago, American Samoa and the PRIA provides scientists with a wealth of integrated ecosystem observations that can be compared and contrasted with information across the Pacific region. During 2006 and 2007, multibeam surveys were conducted to provide baseline maps for a better understanding of the underlying structures and environments that support coral and algal habitats. New benthic habitat research at Palmyra Atoll provides more focused research on Palmyra-specific benthic habitats.

### *Habitat Mapping*

In support of the U.S. Coral Reef Task Force's mission to "produce comprehensive digital maps of all shallow (<30 m) coral reef ecosystems in the United States and characterize priority moderate-depth reef systems," NOAA has initiated comprehensive mapping of the Pacific Islands region. For the PRIA, the USFWS and NOAA purchased and have made available IKONOS imagery that is used as base layers for habitat analyses.

The NOAA Coral Reef Conservation Program supported moderate-depth multibeam mapping surveys in the PRIA during Pacific RAMP cruises in 2006 and 2007. Submersible dives and multibeam surveys in deeper waters were also conducted around Jarvis Island, Kingman Reef and Palmyra Atoll by the Hawaii Undersea Research Laboratory of the University of Hawaii with support from NOAA as documented at http://www.noaanews.noaa.gov/stories2005/s2487.htm.

*Methods*

NOAA multibeam bathymetric surveys were conducted in 2006 and 2007 by personnel from PIFSC-CRED using mapping systems aboard the NOAA Ship *Hi'ialakai* and the survey launch R/V *Acoustic Habitat Investigator* (*AHI*). Bathymetric data were processed aboard ship and grids of the 2006 bathymetric data were published on the Internet in October 2006 at http://www.soest.hawaii.edu/pibhmc. Multibeam backscatter grids, which provide additional information about the roughness and hardness of the seafloor; derivative data products, such as slope, rugosity, and bathymetric position index; and limited optical validation data collected in 2001 are also available at this Web site. These products provide information about benthic habitats in water depths ranging from 3 to 3000+ m with complete bathymetric coverage at all sites except for Johnston, Palmyra and Kingman Atolls (Table 11.3). The total area surveyed in the PRIA is 4461 km$^2$. Multibeam bathymetric surfaces reveal interesting similarities and differences among the seven PRIA discussed here: Baker, Howland and Jarvis are isolated islands that rise from abyssal seafloor (4,000+ m) whereas Kingman, Palmyra, Johnston and Wake have been built on top

*Table 11.3. PRIA Multibeam Coverage. Source: PIFSC-CRED, unpub. data.*

| SITE | WAKE | JOHNSTON | PALMYRA | KINGMAN | BAKER | HOWLAND | JARVIS |
|---|---|---|---|---|---|---|---|
| Survey Date | April 26-30 2007 | Jan. 18-23 2006 | March 24-28 2006 | March 29-April 3 2006 | Jan. 27-29 2006 | Jan. 30-Feb. 1 2006 | March 20-22 2006 |
| Coverage (km$^2$) | 668 | 992 | 1082 | 926 | 221 | 256 | 316 |
| % Completion (10-3,000 m) | 99 | ~85 | ~90 | ~75 | 100 | 100 | 100 |

of larger underlying ridges that are shallower than 4,000 m. These seven PRIA are located in the Central Pacific Basin on seafloor that ranges in age from 83-160 million years ago (Ma). After seafloor formation, extensive Cretaceous (70-100 Ma) volcanism took place throughout the central Pacific.

Geological ages (Clouard and Bonneville, 2005) for the individual islands are only well defined for Johnston Atoll (71.3 Ma), Kingman Reef (69.8 Ma; Davis et al., 2002) and Baker Islands (70.1 Ma; Koppers and Staudigel, 2007). The geologic history of the PRIA is discussed in more detail in the concurrent National Coral Reef Institute 2008 volume on Coral Reefs of the USA (Maragos et al., In press). Baker, Howland and Jarvis are all within one degree of latitude of the Equator and are all steep-sided, very small islands with little evidence of mass wasting on the flanks (Figure 11.17). Baker and Howland Islands are located in the Phoenix Island group on the Tokelau Ridge, while Jarvis Island is one of the four PRIA of the Line Islands group (the others are Johnston, Kingman and Palmyra). The three equatorial PRIA are also located near the Clipperton Fracture Zone. All three are tiny islands with previous sea level stands that can be inferred from small shelf areas that have been detected at up to 500-m depths on the radiating rift zones. The bank areas in shallow water are very limited in size, and there is little potential for coral growth on the steep, deeper flanks of Baker, Howland or Jarvis.

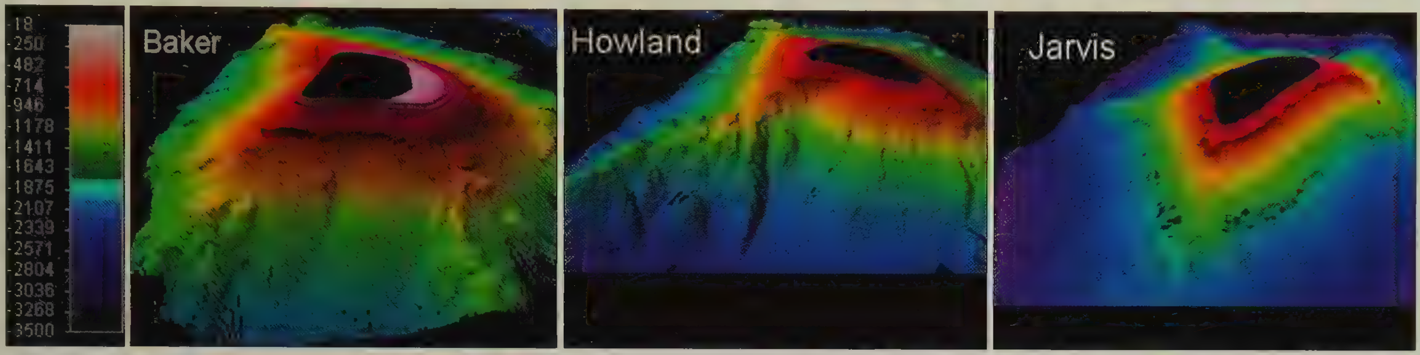

-18
-250
-482
-714
-946
-1178
-1411
-1643
-1875
-2107
-2339
-2571
-2804
-3036
-3268
-3500
Baker
Howland
Jarvis

Figure 11.17. 3-D images of Baker, Howland and Jarvis Island bathymetry. Source: PIFSC-CRED.

In contrast, Palmyra and Wake Atolls, Johnston Atoll and Kingman Reef are morphologically much more complex and highly variable in structure. Johnston is the farthest north of the Line Islands. Although its name implies an atoll, the emergent perimeter reef extends only along the northwest side of Johnston. (Figure 11.18).

Keating's (1987) and Emery's (1956) research strongly suggest that geological forces have caused the bank around Johnston Island to tilt to the southeast. The multibeam bathymetry shows limited areas of shallow (<20 m) offshore bank on the southeast and southwest corners. Moderate-depth multibeam maps show steep slopes on the south and east sides of the banks with extensive evidence of mass wasting on these slopes. Several very narrow shelves occur around the island in depths less than 130 m; such shelves are indicators of previous sea level stands. On the northwest side, there is a 6-8 km wide area of low slope in depths ranging from 500-1,800 m.

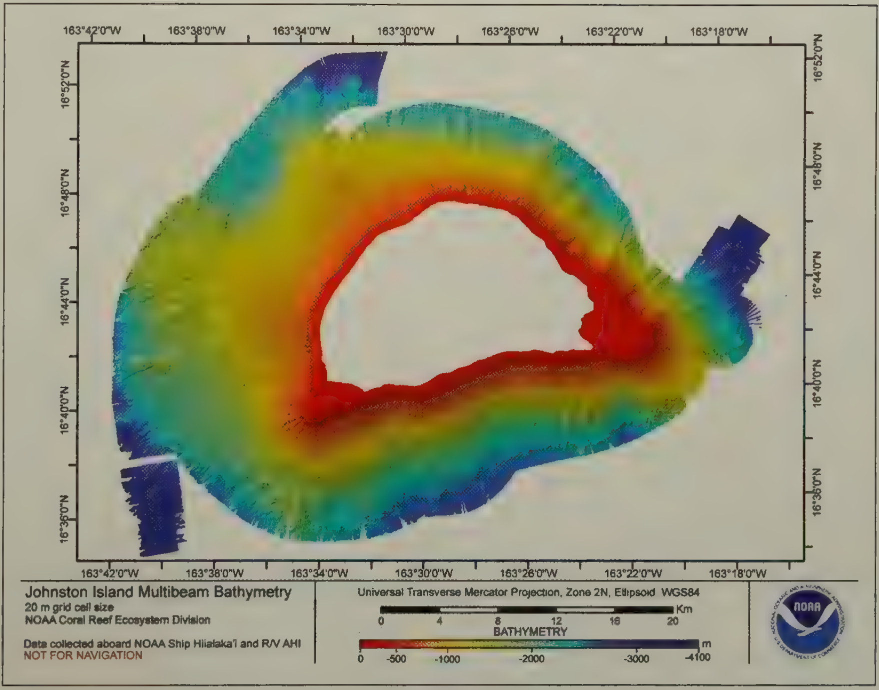

163°42'0"W
163°38'0"W
163°34'0"W
163°30'0"W
163°26'0"W
163°22'0"W
163°18'0"W
16°52'0"N
16°48'0"N
16°44'0"N
16°40'0"N
16°36'0"N
Johnston Island Multibeam Bathymetry
20 m grid cell size
NOAA Coral Reef Ecosystem Division
Data collected aboard NOAA Ship Hiialaka'i and R/V AHI
NOT FOR NAVIGATION
Universal Transverse Mercator Projection, Zone 2N, Ellipsoid WGS84
0
4
8
12
16
20
Km
BATHYMETRY
m
0
-500
-1000
-2000
-3000
-4100
NOAA

Figure 11.18. Johnston Atoll multibeam bathymetric map. Source: PIFSC-CRED.

Palmyra Atoll, Kingman Reef, Christmas Atoll, Fanning Atoll and Washington Island are all located on a broad ridge-like area that is over 1,100 km long and up to 280 km wide. Palmyra has a secondary peak about 3 nm to the west of the atoll that rises to less than 1,000 m (Figure 11.19). The northern flank of the atoll is extremely steep with canyons cutting into the sides to very shallow depths, but the southern flank slopes more gradually. Extensive evidence of mass wasting is seen everywhere except on this steep northern flank. Except for areas with depths less than 20 m, there is no evidence of shelves that would indicate previous sea level stands on the flanks of either Palmyra Atoll or Kingman Reef.

Kingman Reef, located about 50 km north of Palmyra, also lies on a broad ridge-like structure with a secondary peak about 5 km to the west (Figure 11.20). Steep, incised slopes are seen on the northeast, northwest and south sides of the structure. However, anomalous conical structures are seen on the southeast and southwest sides of Kingman and continue to the adjacent bank, following what are likely rift zones. While these might be evidence of mass wasting, they do not occur on the flanks as is expected with erosional features, and the conical shape is more typical of volcanic features.

Wake Atoll (Enen Kio) lies 2,800 km west of Johnston Island in the Marshall Island chain on seafloor that was formed over 160 Ma. No age is available for Wake Atoll, but its neighbor in the Marshall Islands, Enewetak Atoll, was dated at 75.84-76.26 Ma (Clouard and Bonneville, 2005). Beyond the shallow water (<25 m), habitats surrounding the island, Wake Atoll drops off steeply on all sides from 20 to 500 m and almost vertically at the northwest corner (Figure 11.21). No shelf structures occur between 25 and 300 m that would indicate previous sea level stands. However, the ridge that extends out from the southeastern corner of the island has a relatively low slope in depths greater than 500 m and, from nautical charts, appears to extend over 22 km to the east. Evidence of mass wasting is seen on the south and east sides of the island at 2000-3500 m depths.

### Coral Communities in the PRIA

Coral assessment and monitoring activities in the PRIA have continued through the cooperative research efforts of PIFSC-CRED, USFWS and partner institutions noted above, including scientists from SIO, Bishop Museum, University of Hawaii (UH) and Oceanic Institute. Survey techniques are described in detail in the 2005 edition of this report (Brainard et al., 2005) and include REAs and towed-diver surveys that average about 2 km in length. These techniques have focused on collecting data to compute metrics of coral biodiversity, frequency, mean diameter, distribution, abundance, percent cover and size structure.

Since 2005, REA activities have followed the revised protocol established in 2004 (Brainard et al., 2005; Maragos et al. 2004) with several modifications. The line-intercept method was added in 2005 with data collected at 50-cm intervals along the first two 25-m transects to estimate percent cover of live coral and other benthic categories. In 2006 this method was further modified to include all corals whose colony center fell within 0.5 m on each side of the transect line. Quantitative disease assessments, initiated in 2004 at Johnston, Baker and Howland have now been expanded to all REA sites in the PRIA. Extended deployments allowed the establishment of three new REA sites at Johnston and two at Kingman. Figure 11.13 shows the locations of REA sites

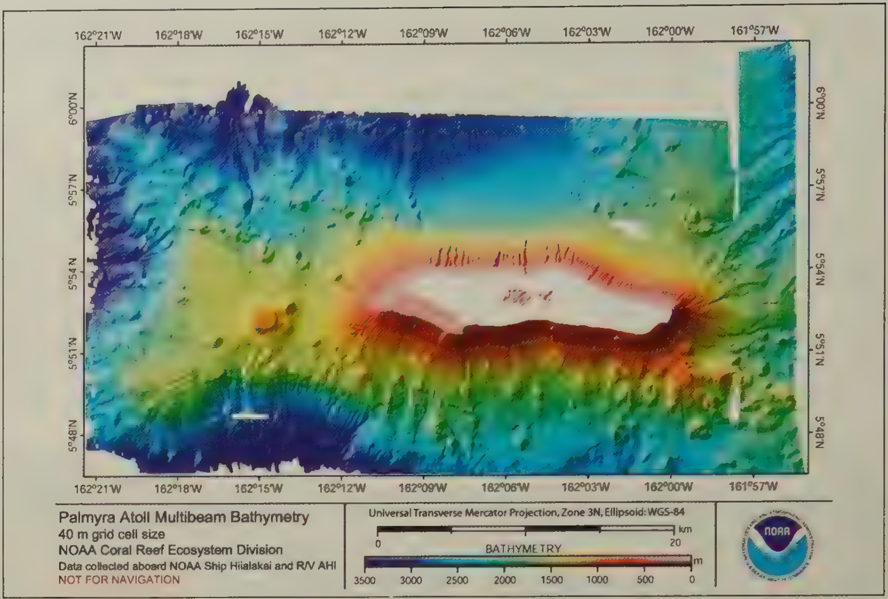

162°21'W
162°18'W
162°15'W
162°12'W
162°09'W
162°06'W
162°03'W
162°00'W
161°57'W
6°00'N
5°57'N
5°54'N
5°51'N
5°48'N
Palmyra Atoll Multibeam Bathymetry
40 m grid cell size
NOAA Coral Reef Ecosystem Division
Data collected aboard NOAA Ship Hiialakai and R/V AHI
NOT FOR NAVIGATION
Universal Transverse Mercator Projection, Zone 3N, Ellipsoid: WGS-84
0
20
km
BATHYMETRY
3500
3000
2500
2000
1500
1000
500
0
m
NOAA

*Figure 11.19. Palmyra Island multibeam Bathymetry. Source: PIFSC-CRED.*

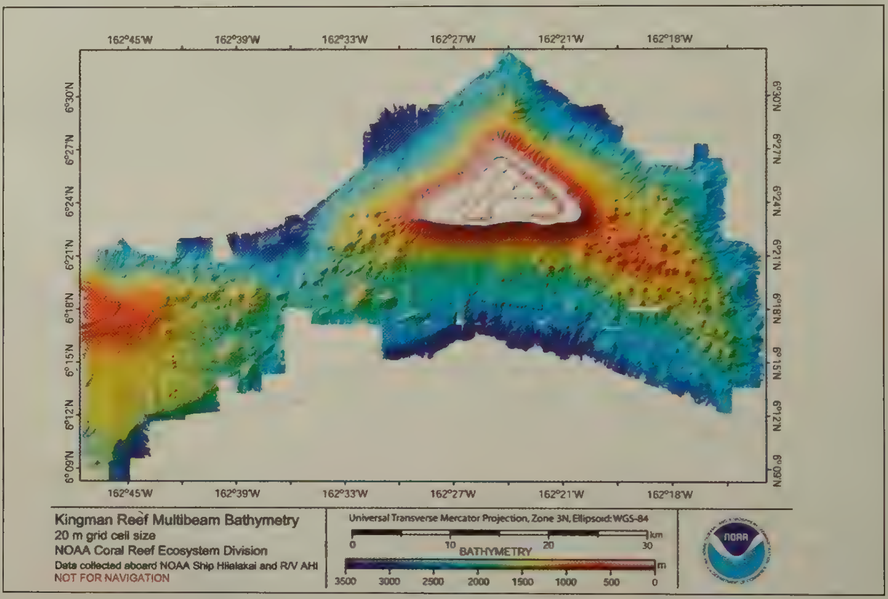

162°45'W
162°39'W
162°33'W
162°27'W
162°21'W
162°18'W
6°30'N
6°27'N
6°24'N
6°21'N
6°18'N
6°15'N
6°12'N
6°09'N
Kingman Reef Multibeam Bathymetry
20 m grid cell size
NOAA Coral Reef Ecosystem Division
Data collected aboard NOAA Ship Hiialakai and R/V AHI
NOT FOR NAVIGATION
Universal Transverse Mercator Projection, Zone 3N, Ellipsoid: WGS-84
0
10
20
30
km
BATHYMETRY
3500
3000
2500
2000
1500
1000
500
0
m
NOAA

*Figure 11.20. Kingman Reef multibeam bathymetry. Source: PIFSC-CRED.*

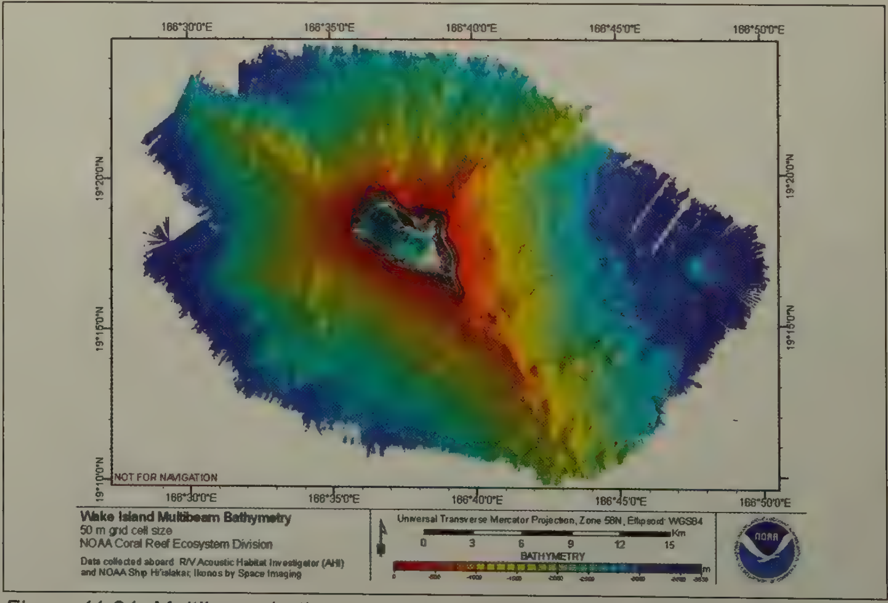

166°30'0"E
166°35'0"E
166°40'0"E
166°45'0"E
166°50'0"E
19°20'0"N
19°15'0"N
19°10'0"N
NOT FOR NAVIGATION
Wake Island Multibeam Bathymetry
50 m grid cell size
NOAA Coral Reef Ecosystem Division
Data collected aboard R/V Acoustic Habitat Investigator (AHI) and NOAA Ship Hi'ialakai; Ikonos by Space Imaging
Universal Transverse Mercator Projection, Zone 58N, Ellipsoid: WGS84
0
3
6
9
12
15
Km
BATHYMETRY
0
m
NOAA

*Figure 11.21. Multibeam bathymetric map of Wake Island. Source: PIFSC-CRED.*

visited between 2005 and 2007. Table 11.4 summarizes the number of study sites at each location.

## *Coral Communities at NWR in the Line and Phoenix Islands in 2006*

### Howland Island Coral Communities

Corals were most recently surveyed at Baker Island NWR and Howland Island NWR between January 28-February 1, 2006, including five REA sites at Howland. As has been the case during prior visits, onshore winds and swells prevented surveys off the eastern half of Howland, except for one site near the south end (HOW 9). Strong currents off the southern and northern reef terraces of the island prevented stationary dives, although towed-diver surveys were successfully completed there. Hence, REA surveys at Howland are still limited in coverage. A total of 98 species and 30 genera of corals and anemones have now been reported from Howland. The species total for cnidarians (stony corals, anemones and corallimorphs) is slightly higher at Howland vis-à-vis Baker, but the generic total at Howland is much lower than at Baker Island (92 species, 38 genera) where all sides of the island and habitats have been surveyed. The mushroom coral (*Podabacia crustacea)* was reported for the first time at Howland in 2006. Table 11.5 summarizes 2006 population data collected at five sites at Howland. Unfortunately, only one REA site (HOW 16, off the NW coast) was surveyed during both 2004 and 2006. At this site, coral cover declined from 60 to 26%, coral densities increased from 2.9-11.4 colonies/m$^2$, and mean coral diameters declined from 50-21 cm. Nevertheless, the surveys elsewhere reveal an increase in coral densities, a shift from larger to smaller corals, and an increase in overall abundance by 2006. The values range from 23-38% live coral cover at three sites in 2004 and 26-65% at five sites in 2006. Density values rose from a range of 2.9-3.9 colonies/m$^2$ in 2004 to a range of 8.1-15.2 colonies/m$^2$ in 2006. In addition, *Psammocora* was abundant in several size classes in 2006 but absent altogether in 2004. Moreover, several genera (*Fungia*, *Hydnophora*, *Leptastrea*, *Pocillopora*) were substantially more common in most size classes in 2006.

*Table 11.4. Summary of coral rapid ecological assessment (REA), permanent transect (PT), and towed-diver (TD) surveys in the PRIA in 2005-2007. Source: PIFSC-CRED.*

| | 2005 | | 2006 | | | 2007 | |
|---|---|---|---|---|---|---|---|
| **Location** | **REA** | **TD** | **REA** | **PT** | **TD** | **REA** | **TD** |
| Wake | 14 | 19 | - | - | - | 12 | 19 |
| Johnston | - | - | 18 | 4 | 27 | - | - |
| Kingman | - | - | 16 | 2 | 22 | - | - |
| Howland | - | - | 6 | 3 | 6 | - | - |
| Baker | - | - | 8 | 4 | 10 | - | - |
| Palmyra | - | - | 13 | 2 | 22 | - | - |
| Jarvis | - | - | 9 | 2 | 12 | - | - |

*Table 11.5. Numbers of corals per genus, frequency, mean diameter and cover by site reported at Howland in January 2006. Bold=increases and italics=decreases since 2004 at sites 5P and 16. Source: J. Maragos, unpub. data.*

| HOWLAND ISLAND NWR 2006 CORAL SITES | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Genus** | **Site Number Number of Corals/Genus** | | | | | **Total / Genus** | **% of Total** |
| | **14P** | **11P** | **5P** | **16** | **10** | | |
| *Acropora* | 60 | 41 | *6* | **30** | 15 | 152 | 5.3 |
| *Cycloseris* | 1 | | **2** | | | 3 | 0.11 |
| *Cyphastrea* | 1 | | | **1** | | 2 | 0.07 |
| *Echinopora* | | | **1** | | | 1 | 0.04 |
| *Favia* | 11 | 5 | **10** | *4* | 15 | 45 | 1.58 |
| *Favites* | 9 | 1 | | **6** | 2 | 18 | 0.63 |
| *Fungia* | 15 | 93 | **74** | **37** | 1 | 220 | 7.74 |
| *Gardineroseris* | 19 | 9 | **3** | **4** | 1 | 36 | 1.27 |
| *Herpolitha* | | 1 | | | | 1 | 0.04 |
| *Hydnophora* | 7 | 7 | 1 | **8** | 56 | 79 | 2.78 |
| *Leptastrea* | 14 | | **20** | *2* | | 36 | 1.3 |
| *Lobophytum* | | 19 | | | | 19 | 0.67 |
| *Montipora* | 59 | 223 | *10* | **51** | 21 | 364 | 12.8 |
| *Palythoa* | | | | **1** | | 1 | 0.04 |
| *Pavona* | 97 | 62 | **52** | **113** | 77 | 401 | 14.1 |
| *Pocillopora* | 115 | 241 | **123** | **259** | 176 | 914 | 32.2 |
| *Podabacia* | | | | **1** | | 1 | 0.04 |
| *Porites* | 79 | 56 | **23** | *46* | 161 | 365 | 12.8 |
| *Psammocora* | 4 | 1 | **1** | **6** | 20 | 32 | 1.13 |
| *Rhodactis* | | | **78** | | | 78 | 2.74 |
| *Tubastraea* | | | | | 74 | 74 | 2.6 |
| **Total No. /Site** | 491 | 759 | **404** | **569** | 619 | 2,842 | 99.98 |
| **Mean Diameter (cm)** | 30 | 22.1 | *25.5* | *20.7* | 23.2 | | |
| **Density (colonies/m$^2$)** | 9.8 | 15.2 | **8.1** | **11.4** | 12.4 | | |
| **No. of Genera** | 14 | 13 | **14** | **15** | 12 | | |
| **% Coral Cover** | 53.8 | 65.3 | **43.5** | *26.1* | 45.5 | | |

### Baker Island Coral Communities

A total of eight REA sites were surveyed at Baker. One dive at site BAK 5 was made to a depth of 30 m to collect photos and sediment samples for toxicity analyses. Collectively, 42 cnidarian and 36 stony coral genera have now been found at Howland and Baker although 15 of these genera are found only at one island or the other. New records for corals at Baker were *Rhizopsammia verrilli* and *Cladopsammia eguchii*. Table 11.6 summarizes all coral population data collected in 2006. Coral species richness was high at all but one site and ranged from 8-11 genera in 2004 compared to a range of 5-13 genera in 2006. Density values ranged from 2-4 colonies/m$^2$ in 2004 to 2-9 colonies/m$^2$ in 2006. Baker site 16p had a lower number of coral genera (five) on the transect compared to other sites, due to the dominant staghorn *Acropora* that monopolized substrates. Abundance of *Acropora* staghorn corals appears to have increased at most stations and survey counts of this genus are collectively among the most abundant corals in the PRIA.

Coral population data were collected at the same three Baker REA sites in 2004 and 2006 (BAK 2, 7 and 9). Coral densities in 2006 at the three sites were substantially higher (8.9, 3.2, 6.5 colonies/m$^2$, respectively) than in 2004. In 2006, the largest corals densities at the three sites were comparable to those observed in 2004, but there was a major increase in the numbers of corals in the 4 smallest size classes. The 2004 percent coral cover estimates for the three sites were 16, 49 and 27%, respectively, compared to 16, 27 and 68%, respectively, in 2006. The red invasive corallimorph, *Rhodactis howesii,* showed a dramatic increase at site BAK 5P in 2006 and is now present at site BAK 11P. Both of these sites served as boat landings, and corroding iron from long-abandoned anchors and chains may be stimulating the growth of this species.

## Jarvis Island Coral Communities

Coral communities were censused at nine Jarvis REA sites between March 21-22, 2006. Calm sea conditions allowed the REA team to survey three sites off the north side of the island and two off the east side, providing more complete coverage than previous surveys at Jarvis. Table 11.7 summarizes the results of coral population censuses at all nine sites. No new genera or species of corals were added in 2006 to the total of 50 species previously reported at the island. The coral fauna at Jarvis is unusual in that it is low in diversity compared to other Line Islands (except Johnston) that have been surveyed for corals during the past several decades. Its geographic isolation and small size may account for this anomaly. Jarvis lies west of the main northwest-southeast axis of the Line Islands, with its nearest neighbors being Kiritimati Atoll (200 nm to the northeast) and Malden Island (350 nm to the southeast). The northern and western sides of Jarvis are exposed to large swells from the northwestern Pacific. Some REA sites that are protected from swells support larger and more numerous corals and high coral cover (JAR 2, 4Pa).

*Table 11.6. Numbers of corals per genus, frequency, mean diameter and cover. Bold=increases and italics=decreases since 2004 at sites 9, 2, 7 and 5P. Asterisk (*)=anemone and two asterisks (**)=corallimorph. Source: Maragos, unpub. data.*

**2006 BAKER ISLAND NWR CORAL SITES**

| Genus | Site Number<br>Number of Corals/Genus | | | | | | | | Total/ Genus | % of Total |
|---|---|---|---|---|---|---|---|---|---|---|
| | **16P** | **9** | **2** | **7** | **5P** | **11P** | **3** | **6** | | |
| *Acropora* | 112 | **166** | **163** | **279** | **254** | 151 | 157 | 190 | 1,472 | 60.7 |
| **Aptasia* | | *0* | | | *0* | | | | 0 | 0 |
| *Cyphastrea* | | **2** | **2** | | **3** | 1 | | | 8 | 0.33 |
| **Entacmaea* | | | | | | | 1 | | 1 | 0.04 |
| *Favia* | | **22** | **6** | *2* | **1** | 9 | 8 | 3 | 51 | 2.1 |
| *Favites* | | **2** | | 2 | | | 1 | 1 | 6 | 0.25 |
| *Fungia* | | **62** | **107** | **5** | | 11 | 102 | 16 | 303 | 12.5 |
| *Halomitra* | | | *0* | **1** | | | | | 1 | 0.04 |
| *Herpolitha* | | | | **1** | **1** | | 2 | | 4 | 0.17 |
| **Heteractis* | | | | | | | 2 | | 2 | 0.08 |
| *Hydnophora* | | *0* | | | | | 1 | | 1 | 0.04 |
| *Leptastrea* | | *0* | **2** | **1** | **1** | 1 | | 1 | 6 | 0.25 |
| *Leptoseris* | | **3** | **8** | *0* | | 2 | | | 13 | 0.54 |
| *Montipora* | | **9** | *4* | *0* | **22** | 2 | 1 | | 38 | 1.57 |
| *Palythoa* | | *0* | **1** | | | | | | 1 | 0.04 |
| *Pavona* | 1 | *4* | **18** | **5** | *1* | 21 | 14 | 1 | 65 | 2.68 |
| *Pocillopora* | 1 | *50* | **118** | *13* | **24** | 31 | 76 | 32 | 345 | 14.23 |
| *Porites* | 1 | *1* | **16** | | **3** | | 5 | 1 | 27 | 1.11 |
| *Psam-mocora* | 1 | *3* | *0* | **1** | | | 2 | | 7 | 0.29 |
| ***Rhodactis* | | | | *0* | **70** | 2 | | | 72 | 2.97 |
| *Tubastraea* | | | **1** | | | | | | 1 | 0.04 |
| **Total No. /Site** | 116 | **324** | **446** | **310** | **380** | 231 | 372 | 245 | 2,424 | 99.97 |
| **Mean Diameter (cm)** | 128 | *37.3* | *16.8* | *26.1* | *16.6* | 22.4 | 24.1 | 28.5 | | |
| **Density (colonies/m$^2$)** | 2.3 | **6.5** | **8.9** | **6.2** | **7.6** | 4.6 | 7.4 | 4.9 | | |
| **No. of Genera** | 5 | 11 | **12** | **10** | **10** | 10 | 13 | 8 | | |
| **% Coral Cover** | 87.2 | **68.3** | 15.9 | *27* | *15.6* | 17.7 | 32.1 | 33.7 | | |

Three REA sites at Jarvis (JAR 1, 8, 10) were surveyed during 2004 and 2006. In all cases coral populations were more abundant and diverse in 2006. Many more corals and higher densities were also reported at all three sites in 2006; density values ranged from 1-2.5 colonies/m$^2$ in 2004 compared to 2-7 colonies/m$^2$ in 2006. Corals in smaller size classes were more numerous in 2006, except one larger size class (41-80 cm in diameter) that was more abundant in 2004. Diversity increased from 3-4 genera/transect in 2004 to 5-8 genera/transect in 2006.

## Johnston Atoll Coral Communities

The first surveys by PIFSC-CRED and USFWS at Johnston were completed in January 2004; the second set of surveys were completed in January 2006. Corals were censused at 17 sites between January 18-23, 2006, including 11 REA sites previously surveyed in 2004. Johnston supports three hydrozoan stony corals (*Millepora*, *Distichopora*, *Stylaster*) not found farther north in Hawaii. Johnston has also historically supported prolific growths of at least 10 species of table corals in the genus *Acropora,* especially within the semi-protected lagoon. Most of these species are believed to have colonized Hawaii (450-800 nm north) via Johnston Atoll (Maragos and Jokiel, 1986). Unexpectedly, the otherwise protean Pacific coral genera of *Porites* and *Pocillopora* contribute only minor fractions of the coral fauna at Johnston compared to *Montipora*, *Acropora* and *Pavona*. Coral REA surveys were accomplished in 2006 at windward ocean-facing fore reef

Table 11.7. Numbers of corals per genus, frequency, mean diameter and cover by site reported at Jarvis Island NWR in January 2006. Bold=increases and italics=decreases since 2004 at sites 8, 1 and 10. Source: J. Maragos, unpub. data.

| 2006 JARVIS ISLAND NWR CORAL SITES | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Genus** | **Site Number<br>Number of Corals/Genus** | | | | | | | | | **Total/ Genus** | **% of Total** |
| | **9** | **8** | **1** | **10** | **4P** | **2** | **12** | **7P** | **11P** | | |
| *Acropora* | | | | *0* | 1 | 3 | | | | 4 | 0.22 |
| *Distichopora* | | | | **87** | | | | | | 87 | 2.69 |
| *Favia* | 2 | | | **1** | | 1 | | 2 | | 6 | 0.22 |
| *Fungia* | 27 | **1** | | | 7 | 1 | 24 | | | 60 | 1.88 |
| *Hydnophora* | | | | | | | 1 | | | 1 | 0.03 |
| *Leptoseris* | 1 | **2** | **1** | **1** | | | | | | 5 | 0.15 |
| *Millepora* | 1 | | | **12** | 6 | | 22 | 3 | 18 | 62 | 1.92 |
| *Montipora* | 182 | **53** | **57** | **8** | 240 | 404 | 71 | 322 | 285 | 1,622 | 50.1 |
| *Pavona* | 23 | **20** | **28** | **34** | | 2 | 13 | 6 | 9 | 135 | 4.17 |
| *Pocillopora* | 123 | **22** | **36** | **243** | 390 | 76 | 71 | 131 | 86 | 1,178 | 36.4 |
| *Porites* | 2 | **1** | **2** | *0* | | | | 16 | 25 | 46 | 1.42 |
| *Psam-mocora* | 2 | **1** | | | | | | | | 3 | 0.1 |
| *Sinularia* | 1 | **2** | **1** | **1** | | | | 17 | | 22 | 0.68 |
| *Tubastraea* | | | | | | | 1 | | | 1 | 0.03 |
| **Total No. /Site** | 364 | 102 | 125 | 387 | 644 | 487 | 203 | 497 | 423 | 3,232 | 100.01 |
| **Mean Diameter (cm)** | 29.3 | *11.3* | *11.5* | *19.4* | 27.4 | 29.9 | 16.1 | 27.2 | 22.9 | | |
| **Density (colonies/m²)** | 7.3 | **2** | **2.5** | **7.7** | 12.9 | 9.8 | 4.1 | 9.9 | 8.3 | | |
| **No. of Genera** | 10 | **8** | **6** | **8** | 5 | 6 | 7 | 7 | 5 | | |
| **% Coral Cover** | 37.7 | *1.8* | **2.4** | *13.4* | 70.8 | 60.4 | 14.1 | 45.2 | 25.7 | | |

sites (JOH 14, 15, 16, 17) for the first time. Coral densities, percent cover and mean diameters were lowest and generic diversity highest at ocean sites. Evidence of persistent wave action and active predation by COTS were observed on the fore reef and are likely the cause of reduced coral abundance. COTS counts yielded 4-5 per 100 m$^2$ at three of the sites. Table 11.8 summarizes results for the 11 sites surveyed in 2004-2006.

Comparisons of coral population size structure at 2004 and 2006 REA sites revealed substantial changes during the two-year interval. All 11 sites showed declines in mean coral diameter, most showed reductions in larger corals and increases in density of smaller coral colonies, and all but one site showed declines in coral cover in 2006. (Table 11.8). Overall, average coral cover declined from nearly 30% in 2004 to 25% in 2006. The number of colonies in the largest size class of table corals (*Acropora cytherea*) declined from 25 in 2004 to 12 in 2006, and all but one of the 41 largest *Montipora* colonies and the four *Pavona* disappeared or fragmented into smaller colonies. The large increase in small *Montipora* colonies in the northern lagoon (JOH 4, 5P, 8, 9, 11,12) was insufficient to offset the loss of larger colonies at the surveyed sites; thus, overall coral cover declined. All but two species (*Fungia* and *Pocillopora*) declined in abundance during the two-year period.

### Palmyra Atoll Coral Communities in 2006

Palmyra has been surveyed for corals on nine occasions since 1987, and more than 190 species and 50 genera of corals and other cnidarians have been reported. Corals were censused at 13 REA sites in March 2006. Calm sea conditions allowed the REA team to expand coverage of REA sites further to the northeast and southeast. Coral surveys in 2006 were more extensive than during any previous surveys. Despite a number of previous efforts, new records continue to be reported, including two during the 2006 visit: the octocoral *Pachyclavularia violacea* and an unidentified scleractinian, *Echinophyllia* sp. The coral faunas at Palmyra and nearby Kingman are much more diverse than at the other surveyed Line Islands. Possible reasons are that Palmyra has been much better sampled, is larger, and has a more varied habitat than neighboring reef islands (Jarvis, Teraina, McKean, Howland, Baker). Both Palmyra and Kingman are often in the path of the eastward-flowing NECC, which may transport larvae of additional coral species from the more diverse western Pacific. Table 11.9 summarizes the characteristics of coral populations at all Palmyra 2006 REA sites.

Six of the REA sites at Palmyra (PAL 1, 10, 16P, 19, 25, 26) were surveyed both in 2004 and 2006; all of them are located on the south side of the atoll. At all sites coral populations showed larger mean colony diameters and lower density values, except for a slightly higher density value at site PAL 1 in 2004. Much of the shift to a smaller mean size is attributed to more numerous small coral recruits in 2006. The soft coral *Lobophytum* showed phenomenal increases in 2006, and another octocoral, *Stereonephthya* also increased in abundance. The stony lobe coral *Porites*, and disc coral *Pavona*

*Table 11.8. Coral population characters, numbers of corals per genus and coral size frequency distributions in 2006 at the same 11 sites surveyed in 2004.* Bold=increase and *italics*=decrease in values since 2004. *Source: J. Maragos, unpub. data.*

| **CORAL POPULATION CHARACTERS AT JOHNSTON SITES RESURVEYED IN 2006** | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Site Number<br>Number of Corals/Genus** | | | | | | | | | | | **2004** | **2006** |
| | *1* | *2* | *3* | *4* | *6* | *7* | *8* | *9* | *10P* | *11* | *12* | **MEANS** | |
| **Mean Diameter (cm)** | 22.1 | 18.6 | 16.7 | 8.8 | 36.9 | 16.1 | 7.9 | 10.2 | 18.3 | 23.5 | 21.5 | **28.9** | *18.24* |
| **Density (colonies/m²)** | **9.3** | **11.7** | **7.5** | **42.6** | 1.4 | **9.5** | **13.6** | **15.2** | **7.1** | **10.8** | **12.5** | *5.49* | **12.84** |
| **No. of Genera** | 4 | 4 | **5** | 3 | 6 | **6** | **7** | **6** | 4 | 4 | **5** | *4.45* | **4.9** |
| **% Coral Cover** | **52.6** | **53.9** | 7.06 | **20.7** | 14.2 | 8.57 | 5.53 | 7.92 | 20.4 | 45.9 | 38.6 | **29.66** | *25.03* |
| **NUMBER OF CORALS/GENUS AT 11 JOHNSTON SITES RESURVEYED IN 2006** | | | | | | | | | | | | **TOTALS** | |
| *Acropora* | *14* | *6* | *36* | **18** | *34* | **61** | *20* | *3* | *10* | **13** | 7 | **302** | *222* |
| *Fungia* | | *0* | | | *0* | | **15** | | | | **1** | *11* | **16** |
| **Heteractis* | | | **1** | | | | | | | | | *0* | **1** |
| *Leptastrea* | | | | | | **2** | | **1** | | | | *0* | **3** |
| *Millepora* | | | | | 2 | | **25** | *2* | | *0* | | *12* | **29** |
| *Montipora* | **419** | **564** | *260* | **2112** | **30** | **257** | **600** | **733** | **382** | **441** | **615** | *3,128* | **6,413** |
| *Pavona* | 2 | *1* | *61* | | 1 | **101** | **18** | **16** | *1* | **50** | *1* | **331** | *252* |
| *Pocillopora* | **31** | **16** | **19** | *0* | 2 | **48** | *4* | *4* | *0* | **36** | **2** | *84* | **162** |
| *Porites* | | | | | **2** | **4** | | | | | | *0* | **6** |
| *Sinularia* | | | | | | *0* | | | | | | **1** | *0* |
| **CORAL SIZE FREQUENCY DISTRIBUTIONS AT 11 RESURVEYED 2006 SITES** | | | | | | | | | | | | **TOTALS** | |
| 1-5 cm | **33** | **133** | *59* | **776** | **17** | **60** | **503** | **392** | **36** | **153** | **73** | *731* | **2235** |
| 6-10 cm | **96** | **125** | *127* | **829** | *19* | **181** | *66* | 196 | **162** | **119** | **181** | *999* | **2,101** |
| 11-20 cm | **182** | **149** | *93* | **434** | *6* | **144** | *59* | 81 | **96** | **90** | **146** | *880* | **1,480** |
| 21-40 cm | **109** | **137** | *79* | *81* | *11* | **61** | *34* | **60** | **80** | **90** | **154** | *753* | **896** |
| 41-80 cm | **40** | *38* | *17* | *10* | *11* | **23** | *17* | *29* | *15* | **71** | **66** | **412** | *337* |
| 81-160 cm | *1* | *4* | 2 | *0* | *3* | *4* | *3* | *1* | *0* | *13* | *5* | **135** | *36* |
| >160 cm | *3* | *1* | *0* | | *4* | *0* | *0* | *0* | **4** | *4* | *1* | **50** | *17* |
| **TOTALS** | **466** | **587** | *377* | **2130** | *71* | **473** | **682** | **759** | **393** | **540** | **626** | 3,869 | **7,104** |

showed increases in small and medium size classes at most sites. The brain corals and relatives (*Montastrea*, *Leptastrea*, *Lobophyllia*, *Hydnophora and Favites*) and the agaricid corals (*Gardineroseris* and *Leptoseris)* all showed increases at one or more sites in 2006, with no coral genera showing declines over the same period. At PAL 6 a corallimorph, *Rhodactis howesii,* is undergoing a population explosion likely stimulated by dissolved iron from the 1991 long-liner wreck site just north of the dredged channel. This site should be added for future intensive monitoring since the corallimorph appears to be reaching nuisance/invasive levels quickly. Additional observations in September 2007 (Work and Aeby, 2007) reveal that the corallimorph has now spread to areas more than 2 km from the wreck and has colonized other reef sites where iron chains, buoys and moorings have been established.

## Kingman Reef Coral Populations 2006

Kingman has been surveyed for corals on seven occasions since 2000. Table 11.10 summarizes the results of the 2006 coral censuses at the 13 REA sites. Until 2005-2007, very little survey effort had been focused on the western half of the atoll reef, ocean reefs off the east tip and the northeast fore reef. Nevertheless, more than 180 species and 53 genera of corals and other cnidarians have already been reported at Kingman, including a new record of the genus *Pachyseris* at the far western end (site KIN 22) in depths of 30-35 m. Several species of corals belonging to the genera *Porites* and *Acropora* have yet to be described.

Six 2004 REA sites, including four in the lagoon (KIN 3, 7, 8, 12) and two off the south ocean reef (KIN 11, 13), were resurveyed in 2006. The range in mean diameters were higher for all six sites in 2004 were substantially larger in 2006 (ranging from 17 to 47 cm) than at the same sites in 2006 (ranging from 11 to 22 cm). However, the colony frequency levels at all six 2006 sites ranged from 9.4 to 32.2 colonies/m², two or three times higher than the counterpart 2004 frequencies (4.4 to 6.8 colonies/m²). Large numbers of smaller corals recruited to all six sites during the two-year period, helping to explain these trends. Corals in the smallest size class were substantially more abundant in 2006. Only the two oceanic sites (KIN 11, 13) surveyed in 2004 showed a greater abundance of corals in the two largest size classes in 2006. None of the 38 coral genera posted decreases in abundance and most posted increases in 2006. The large influx of corals of many types and size classes during the two-year period serve as positive indicators of the healthy status of coral populations at Kingman Reef.

Table 11.9. 2006 data on coral generic diversity, density, percent cover and mean diameter at the same seven REA sites surveyed in 2004 at Palmyra Atoll NWR. Bold=increase and italics=decrease in values since 2004. Source: J. Maragos, unpub. data.

| PALMYRA ATOLL NWR CORAL SITES RESURVEYED IN 2006 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Genus | Site Number<br>Number of Corals/Genus | | | | | | | TOTALS AT ALL 13 SITES | % OF TOTAL |
| | 25 | 10 | 19 | 26 | 1 | 16P | 15P | | |
| *Acropora* | **3** | *2* | **1** | **1** | *0* | **14** | 208 | 252 | 3.1 |
| *Astreopora* | *0* | | | **4** | | | **33** | 38 | 0.47 |
| *Cladiella* | | **3** | | | | | | 27 | 0.33 |
| *Cycloseris* | | | **3** | **2** | | | | 5 | 0.061 |
| *Cryptodendrum** | | | | | *0* | | | 0 | 0 |
| *Distichopora* | | **1** | | | | | | 1 | 0.01 |
| *Echinophyllia* | | *1* | | | | | | 3 | 0.036 |
| *Favia* | **26** | **57** | **38** | **22** | *8* | **4** | **6** | 331 | 4.1 |
| *Favites* | *1* | *11* | **25** | **14** | | *0* | | 159 | 1.96 |
| *Fungia* | **29** | **56** | **30** | **2** | **37** | *20* | *6* | 506 | 6.2 |
| *Gardineroseris* | | **8** | 1 | | | | | 10 | 0.12 |
| *Halomitra* | **3** | *0* | | | | | | 3 | 0.036 |
| *Herpolitha* | | *1* | 1 | **1** | | | | 16 | 0.2 |
| *Heteractis** | **1** | | | | | | | 1 | 0.012 |
| *Hydnophora* | **8** | *8* | **21** | **18** | *0* | | | 116 | 1.43 |
| *Leptastrea* | **4** | **7** | **8** | **2** | | | **21** | 86 | 1.06 |
| *Leptoseris* | **13** | **16** | **9** | *1* | *1* | | | 85 | 1.05 |
| *Lobophyllia* | **8** | **42** | *5* | | *15* | | | 111 | 1.37 |
| *Lobophytum* | **97** | **85** | **171** | **13** | **4** | | | 1,080 | 13.3 |
| *Millepora* | | | | *0* | | | | 1 | 0.012 |
| *Montastrea* | **2** | **4** | **12** | **22** | **1** | | **3** | 122 | 1.5 |
| *Montipora* | **9** | **13** | **15** | **24** | *1* | **41** | *275* | 476 | 5.9 |
| *Palythoa* | **9** | 12 | **8** | **9** | *0* | | | 92 | 1.13 |
| *Pavona* | **43** | **81** | **71** | **69** | *20* | 7 | **8** | 819 | 10.1 |
| *Platygyra* | **4** | *1* | **15** | **5** | | | | 65 | 0.8 |
| *Pocillopora* | **28** | **92** | **126** | **96** | *58* | **140** | *53* | 1,219 | 15 |
| *Porites* | **194** | **131** | **228** | **189** | **58** | *0* | **2** | 1,462 | 18 |
| *Psammocora* | *1* | **7** | **9** | *0* | **3** | **1** | | 62 | 0.76 |
| *Sandalolitha* | *0* | | **1** | *0* | | | | 1 | 0.012 |
| *Sarcophyton* | *34* | *22* | *11* | *15* | *0* | | | 466 | 5.7 |
| *Sinularia* | | | *0* | | | | | 0 | 0 |
| *Stichodactyla** | *0* | | | | | | | 0 | 0 |
| *Sterionephthya* | **5** | **1** | | **23** | | | | 44 | 0.54 |
| *Stylaster* | **24** | 4 | | 6 | | | | 55 | 0.68 |
| *Stylocoeniella* | | | *0* | | | | | 0 | 0 |
| *Stylophora* | **13** | **2** | | | | | | 84 | 1.03 |
| *Turbinaria* | **35** | **10** | **151** | **53** | | | | 354 | 4.36 |
| **Total No. /Site** | **594** | **677** | **960** | **589** | *206* | **227** | **615** | 8,257 | 101 |
| **Mean Diameter (cm)** | **22.7** | *18.2* | *19.9* | *24.4* | *12.5* | *13.7* | *24.3* | | |
| **Frequency** | **12.6** | **13.5** | **19.2** | **11.8** | *4.1* | **4.5** | **11.6** | | |
| **No. of Genera** | **24** | **26** | 23 | **21** | *11* | 7 | *10* | | |
| **% Coral Cover** | *49.4* | **31.4** | **66.7** | **65.5** | *6.3* | *5.81* | *54.4* | **Mean: 36.8%** | |

Table 11.10. Coral generic diversity, density, percent cover and mean diameter at the seven REA sites surveyed in 2004 and 2006 at Kingman Reef NWR. Bold=increase and italics=decrease in values since 2004. Regular text indicates no change/no comparisons possible. Asterisk (*)=anemone and two asterisks (**)=corallimorph. Source: J. Maragos, unpub. data.

| **Genus** | **Site Number Number of Corals/Genus** | | | | | | | **TOTALS AT ALL 13 SITES** | **% OF TOTAL** |
|---|---|---|---|---|---|---|---|---|---|
| | **11** | **13** | **8** | **7** | **12** | **3** | **5P** | | |
| *Acropora* | **16** | **34** | | *3* | *0* | **1** | *0* | 163 | 1.7 |
| *Alveopora* | | | | | *0* | **4** | | 7 | 0.07 |
| *Astreopora* | | | 2 | **3** | 2 | **18** | | 25 | 0.26 |
| *Cladiella* | **66** | *1* | | *0* | | | | 77 | 0.79 |
| *Cryptodendrum** | **1** | | | | | | | 2 | 0.02 |
| *Cycloseris* | | | | | **1** | | | 8 | 0.08 |
| *Distichopora* | **2** | | | | | | | 2 | 0.02 |
| *Echinophyllia* | **8** | | *8* | *0* | | | **2** | 17 | 0.18 |
| *Favia* | **58** | **87** | 18 | *28* | **9** | **20** | **42** | 804 | 8.3 |
| *Favites* | **24** | **15** | *0* | *13* | **5** | **3** | 1 | 287 | 2.96 |
| *Fungia* | **79** | **220** | **11** | *6* | *4* | *20* | *636* | 1,687 | 17.4 |
| *Gardineroseris* | 1 | *0* | | | | | | 11 | 0.11 |
| *Goniastrea* | | | | *0* | **2** | **3** | | 7 | 0.07 |
| *Halomitra* | **4** | | | | | | | 5 | 0.05 |
| *Herpolitha* | **4** | | 1 | | 6 | **5** | **2** | 21 | 0.22 |
| *Heteractis** | | **1** | | | | **2** | | 8 | 0.08 |
| *Hydnophora* | **11** | **14** | *0* | **4** | *1* | **2** | | 50 | 0.52 |
| *Leptastrea* | **18** | **3** | **4** | **5** | **10** | **4** | **3** | 62 | 0.64 |
| *Leptoseris* | **3** | **4** | | | | *0* | | 10 | 0.1 |
| *Lobophyllia* | **20** | **23** | | | | | | 43 | 0.44 |
| *Lobophytum* | *0* | **72** | **87** | **71** | **107** | **55** | **6** | 631 | 6.51 |
| *Millepora* | | **1** | | *0* | | | | 2 | 0.02 |
| *Montastrea* | 1 | **1** | | **26** | **3** | 1 | | 55 | 0.57 |
| *Lobophyllia* | **20** | **23** | | | | | | 43 | 0.44 |
| *Lobophytum* | *0* | **72** | **87** | **71** | **107** | **55** | **6** | 631 | 6.51 |
| *Millepora* | | **1** | | *0* | | | | 2 | 0.02 |
| *Montastrea* | 1 | **1** | | **26** | **3** | 1 | | 55 | 0.57 |
| *Montipora* | **15** | **35** | *0* | *25* | 41 | **18** | *20* | 360 | 3.72 |
| *Pachyclavularia* | **30** | **33** | **1** | **12** | | **8** | | 89 | 0.92 |
| *Palythoa* | **8** | | | **1** | | | | 36 | 0.37 |
| *Pavona* | **31** | **60** | 2 | **5** | *1* | **9** | **2** | 666 | 6.88 |
| *Platygyra* | **12** | | **3** | *2* | | **2** | | 31 | 0.32 |
| *Pocillopora* | **47** | **124** | *d* | **13** | **1** | *4* | *0* | 578 | 5.97 |
| *Porites* | **228** | **174** | **238** | **240** | **296** | **244** | **176** | 3,277 | 33.8 |
| *Psammocora* | **2** | | *2* | **9** | *1* | **25** | | 59 | 0.61 |
| *Rhodactis*** | | | | | 2 | | | 12 | 0.12 |
| *Sandalolitha* | | **2** | | | | | | 3 | 0.03 |
| *Stylaster* | 2 | | | | | | | 4 | 0.04 |
| *Stylophora* | **2** | **24** | | | | | | 27 | 0.28 |
| *Turbinaria* | **28** | **7** | **61** | **18** | **110** | **15** | **6** | 462 | 4.77 |
| *Sarcophyton* | *1* | *0* | **33** | *8* | *2* | **6** | | 82 | 0.84 |
| *Sinularia* | *0* | | **3** | *0* | **6** | **4** | **1** | 16 | 0.16 |
| **Total No. /Site** | **594** | **935** | **466** | **492** | **610** | **473** | *897* | 9,686 | 99.94 |
| **Mean Diameter (cm)** | *22.8* | *14* | *16.9* | *13.6* | *12.2* | *16.9* | **18.5** | | |
| **Density (colonies/m²)** | **14.4** | **18.7** | **9.3** | **9.8** | **12.2** | **9.5** | *17.9* | | |
| **No. of Genera** | *28* | **21** | *14* | 19 | **20** | **23** | **12** | | |
| **% Coral Cover** | *52.9* | 42.1 | **21.5** | **20.7** | **17.1** | *25.7* | *49.6* | **Mean: 29.51 %** | |

## Wake Atoll Coral Communities

REA surveys were conducted at Wake Atoll in October 2005 and April and May 2007 by PIFSC-CRED using methods that have been applied at other Pacific reef locations since 2002. In 2005, REA surveys were conducted at 13 sites and a qualitative snorkel survey assessing occurrence of coral taxa was conducted at one back reef site. In 2007, only the 12 fore reef sites were resurveyed. Only two coral surveys at Wake were accomplished before the 2005 Pacific RAMP surveys. Together these studies included 50 scleractinian species representing 23 genera, two *Millepora* (Class Hydrozoa) species and an unspecified suite of octocorals.

During 2005 surveys at Wake, at least 92 cnidarian taxa were recognized, photographed and/or collected including 81 putative scleractinian species: an additional four or five *Montipora* sp. that appeared to be distinct but whose identification is still under investigation, a hydrozoan, a zoanthid and five octocoral genera. This makes a total of 102 scleractinian taxa currently reported from Wake Atoll. Of the 81 putative scleractinian species, at least 46 were new records, as were the zoanthid and all five octocoral genera. There were no new cnidarian records resulting from 2007 Pacific RAMP surveys.

*Pocillopora*, *Montipora*, *Goniastrea* and *Favia* dominated the coral fauna at fore reef sites. Octocorals accounted for 10.2% of colonies enumerated in 2005 and 8.3% in 2007. The relative contribution of taxa to the coral fauna was highly similar in 2005 and 2007, indicating that August 2006 Typhoon Ioke did not have a selective pruning effect on fore reef coral composition at 10-17 m depths.

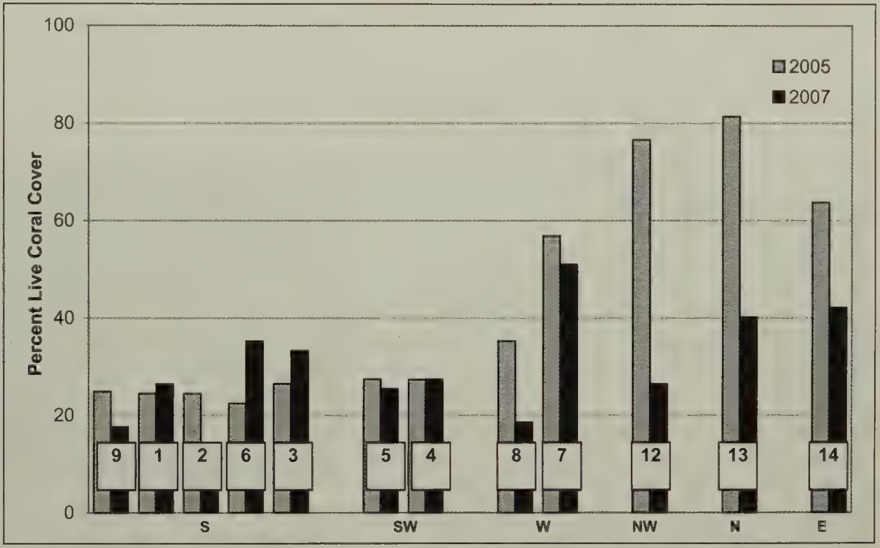


Figure 11.22. Percent live coral cover at 12 fore reef sites at Wake Atoll surveyed in 2005 and 2007. Site numbers are shown at the base of each column. Sites are arranged by geographic sector. S=south, SW=southwest; W=west; NW=northwest; N=north; and E=east. Source: PIFSC-CRED, unpub. data.

In 2005 coral cover at fore reef sites ranged from 22.5–81.4% (Figure 11.22) which seemed to correlate with degree of exposure to oceanographic wave and swell conditions. Low coral cover values were consistently found along south and southwestern exposures, while high coral cover values were found along west and east exposures. The highest coral cover was found along northwest and north exposures. Coral cover at the single site assessed in the lagoon was 14.7%.

In 2007, coral cover at fore reef sites ranged from 10.8%– 51.0%. Sites (12, 13 and 14) that were in the path of Super Typhoon Ioke exhibited the greatest changes in percent live coral cover. These three sites experienced, on average, a decrease in percent live coral cover of more than 37%, compared to average changes of 2.7% for all the other sites combined. Despite the strength of Typhoon Ioke, site-specific surveys did not reveal evidence of storm damage such as dislodged or toppled colonies or bottom scouring. There was no statistically significant difference in overall coral cover ($p > 0.05$) at fore reef sites based on the 2005 and 2007 data.

The size class distribution of anthozoan colonies occurring within fore reef belt transects indicates these communities are characterized by an abundance of large (>20 cm maximum diameter) colonies, particularly when compared to Guam, the closest geographic region surveyed by PIFSC-CRED using similar methods. The close similarity of the 2005 and 2007 distribution of anthozoans is another line of evidence suggesting Typhoon Ioke did not have a substantial effect on the fore reef communities at Wake Atoll at in depths of 10-17 m.

### *Towed-diver surveys*

In 2005, estimates of hard coral cover derived from towed-diver surveys at Wake averaged 32% (range 1–75%). The highest coral cover was noted during two surveys in the southwest corner (average 42% and 37%), and the lowest coral cover (1–5%) was found near the channel to the small boat harbor.

In 2007, estimates of hard coral cover averaged 19% (range 1– 50%). The highest cover (mean 29%) was recorded during a survey near the southwest corner of the atoll (Figure 11.23).

As noted from REA surveys, storm damage from Typhoon Ioke was much less than expected. Several large *Porites* colonies (>1 m diameter) along the eastern shore appeared to have been severed from their bases (Figure 11.24), but the vast majority of colonies was intact and appeared healthy. Small clumps of branches from terrestrial shrubs or trees were packed into small crevices at depths of 13–30 m along the southeast fore reef. No other storm damage was noted. The 2007 towed-diver surveys outside the harbor entrance near the shipwreck of the R/C *Stoner* noted a marked increase in cyanobacteria that was not observed in 2005.

### Summary Findings For Coral Reef Communities in the Seven PRIA

The quantitative REA data document important characteristics of the benthic assemblages in the PRIA and provide an opportunity to monitor for change in response to alterations in the reef environment at a larger scale. An abridged analysis of these data indicates that live coral cover in excess of 40% commonly occurred in protected, leeward, and lagoon habitats (Figure 11.25). Conversely, coral cover in wave- and swell-exposed habitats generally did not exceed 20%. Howland and Jarvis reported the highest mean percent live coral cover, and both exhibited prolific coral reef development along west-facing shores. Differences among the oceanic atolls (Johnston, Wake, Palmyra and Kingman) in mean percent live coral cover were not statistically significant ($p=0.76$; one-way ANOVA).

Towed divers recorded three different estimates pertaining to coral cover (hard coral, stressed coral as a subset of hard corals, and soft corals) at all seven PRIA during the period 2005-2007 (Figure 11.26). The data reveal that Howland (35%), Baker (33%) and Wake (2005: 32%) had the highest cover of hard corals followed by Kingman (25%). However, when both hard and soft corals are combined, Palmyra (44%), Kingman (41%), Baker (38%), Wake (2005: 38%) and Howland (36%) reported the highest combined coral cover. Conversely, the lowest combined coral cover was observed at Jarvis (24%), Johnston (25%), and Wake (2007: 28%).

## Algae

During the 2006 Pacific RAMP surveys, quantitative algal monitoring continued with 15 sites surveyed in the Phoenix Islands (six at Howland, nine at Baker), 35 sites surveyed in the U.S. Line Islands (nine at Jarvis, 12 at Palmyra, 14 at Kingman) and 18 sites surveyed at Johnston Atoll. Quantitative algal sampling began for the first time at Wake Island with 14 sites surveyed in 2005, of which 12 sites were resurveyed in 2007. Previously, only two reports on the flora of Wake Island had been published (Tsuda et al., 2006; USFWS, 1999). Continued use of the algal monitoring protocol established in 2003 (Preskitt et al., 2004) assured uniformity of data sets for statistical temporal analyses. However, at poorly sampled sites such as Wake Atoll, many new records of range extensions are still being found. As a result, results of temporal analyses should be viewed cautiously until a uniform baseline is established.

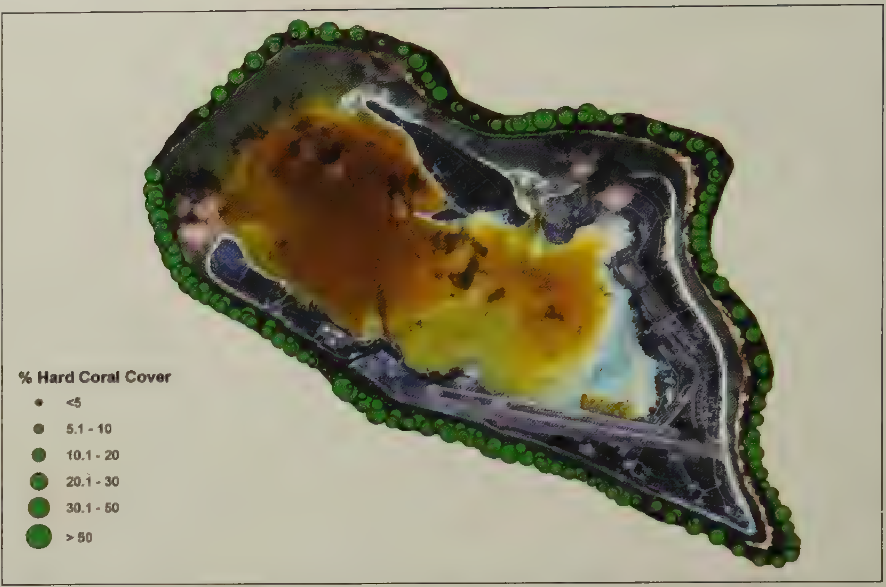


*Figure 11.23. Percentage of (live) hard coral cover around Wake Atoll from towed-diver benthic surveys in 2007. Each colored point represents an integrated estimate over a five-minute observation segment covering a survey swath of approximately 150–250 x 10 m (about 1,500–2,500 m$^2$). Source: PIFSC-CRED, unpub. data.*

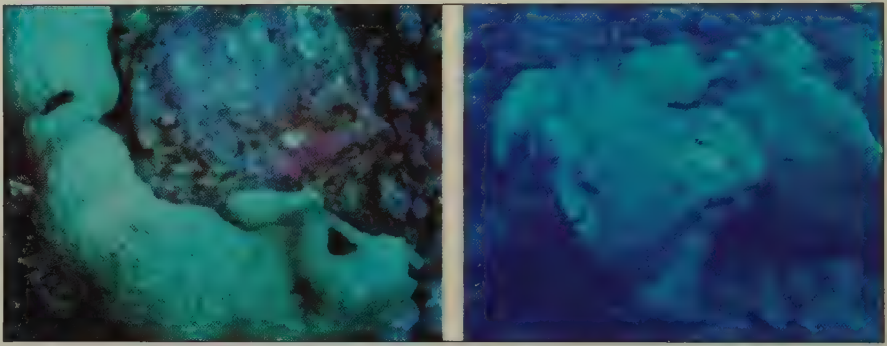


*Figure 11.24.* Porites *colonies that appeared to have been recently detached and subjected to high levels of wave and/or current energy along the eastern fore reef of Wake Atoll. Photos: PIFSC-CRED.*

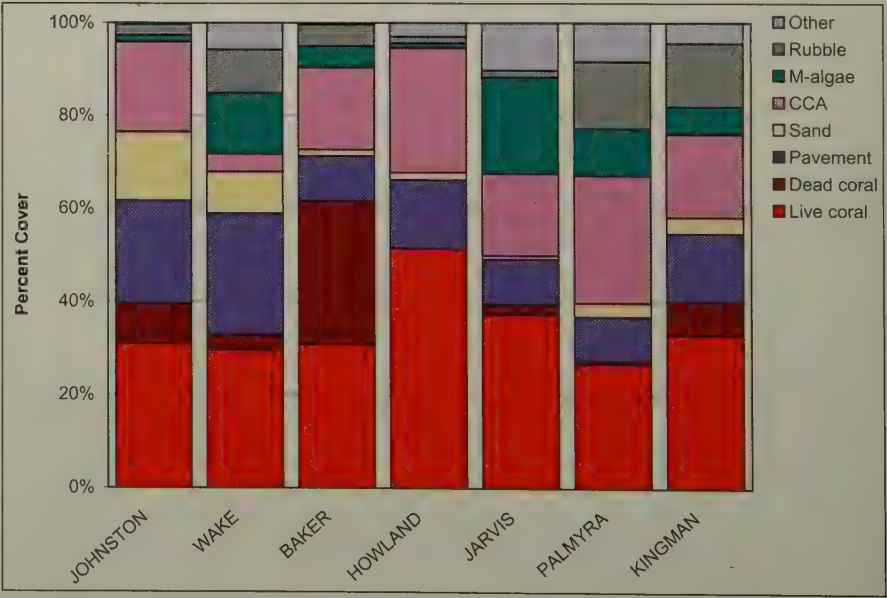


*Figure 11.25. Patterns of variability in percent benthic cover, derived from 80 independent REA surveys in 2006-2007. Source: PIFSC-CRED, unpub. data.*

A joint effort between PIFSC-CRED and the Bishop Museum is addressing algal biodiversity at many of the PRIA, based on PIFSC-CRED collections and other surveys (Tsuda et al. in review; Table 11.11). For Howland and Baker Islands, 85%

of species reported are new records for these locations. For Jarvis Island and Kingman Reef (analyses underway) 100% of the species are new, since no algal collections from these geographic locations have been described in past literature. Algal collections from Palmyra, Johnston, and Wake remain frozen at PIFSC-CRED and are awaiting critical taxonomic analyses.

Preliminary analyses of the Wake Atoll flora suggest many new records. Despite the passage of Typhoon Ioke in August 2006, the only obviously disturbed site (from an algal community viewpoint) was near a dredged channel on the south side that separates Wilkes and Wake Islands. Cyanobacteria there were overgrowing all substrates and on algae that is typically epiphyte-free (e.g., *Liagora* spp.). This site also had large amounts of metallic debris from a nearby shipwreck. The disturbed nature of the site was not considered a result of Super Typhoon Ioke.

Multivariate statistical analyses of species-level benthic cover and fish abundance at Howland and Baker Islands find the two islands to be biologically distinct from each other despite the fact that they lie only 60 km apart (Vroom et al., in preparation). Using data collected in 2004, combined algal functional groups (not including cyanophytes) occupied 55-84% of the substratum at these islands, while corals occupied only 15-45% of the substratum. Macroalgal cover was greater than or equal to coral cover at 50% of the Howland and Baker sites, while crustose coralline red algal cover was greater than coral cover at 80% of the sites. Similar studies on the remaining PRIA are pending.

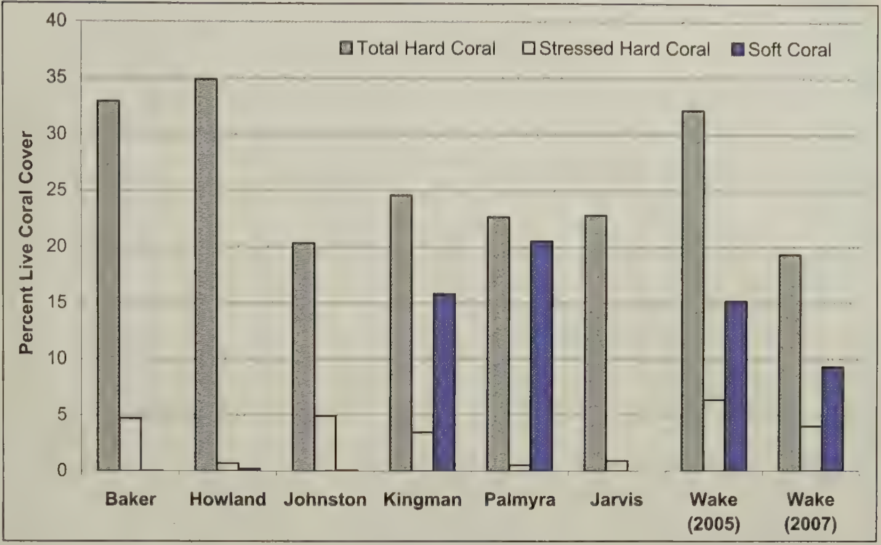


*Figure 11.26. Coral cover from 2005–2007 towed-diver surveys in the PRIA. Source: PIFSC-CRED, unpub. data.*

*Table 11.11. Tentative number of marine benthic algal species identified from Howland, Baker, and Jarvis Islands and Wake Atoll. Wake Atoll numbers include past findings, plus 14 tentative new records for 2007. Laboratory examination of turf algal communities will likely raise the numbers. Source: Tsuda et al., 2006.*

| Island | Cyanophyta | Rhodophyta | Chrlorophytal | Phaeophyta | Totals |
|---|---|---|---|---|---|
| Howland | 3 | 25 | 15 | 4 | **47** |
| Baker | 6 | 48 | 22 | 7 | **83** |
| Jarvis | 5 | 84 | 21 | 5 | **115** |

Vroom et al. (2006a) compared percent cover of macroalgal, turf algal crustose-coralline algal and coral populations at eight islands across the Pacific Ocean basin, including Howland, Baker and Jarvis Islands. Relying on 2004 data, Howland and Baker Islands exhibited among the highest percent cover of living coral (about 30%) of all islands compared, the lowest turf algal cover and the highest crustose-coralline red-algal cover. Heterogeneity of benthic substrate cover around the islands revealed that dense coral communities are limited to certain oceanographic and environmental regimes, underscoring the necessity to protect relatively small coral-dominated areas.

## ASSOCIATED BIOLOGICAL COMMUNITIES

Results from quantitative assessment and monitoring of shallow reef fish assemblages at the PRIA by PIFSC-CRED from 2000 to 2004 are summarized in previous State of the Reef Reports (Turgeon et al., 2002, Brainard et al., 2005). Results from the 2005 and 2007 surveys are summarized here. Quantitative belt transects, stationary point counts (SPC), random swims (for species presence) and towed-diver fish surveys (for large fishes) were conducted at previously visited sites and some new sites, using the same PIFSC-CRED methodology as in previous years. See the PRIA chapter in the 2005 edition of this report for additional details.

### *PRIA Regional Summary for Fish*

Reef fish populations in the PRIA continued to exhibit some of the highest densities and biomasses surveyed by PIFSC-CRED in the Pacific. Jarvis Island was the most notable with the highest target species densities (snappers, groupers, jacks and sharks; Figure 11.27) and the highest large fish biomass (>50 cm total length or TL; 1.5 ton ha$^{-1}$; Figure 11.28) of all PIFSC-CRED-surveyed islands. Wake Island was a distant second for large fish biomass at 0.5 ton ha$^{-1}$, although this is still exceptionally high compared to most reefs around the Pacific. The U.S. Line and Phoenix Islands had similarly high large fish biomasses at around 0.3 ton ha$^{-1}$, although medium-sized target species densities were much higher around the Phoenix Islands. Johnston Atoll had the lowest target species densities and large fish biomass (0.05 ton ha$^{-1}$) of the PRIA. The values from Johnston are more similar to those found at populated islands such as Tutuila in the Territory of American Samoa.

### *Howland and Baker Islands (2006)*

Fish were resurveyed around Howland and Baker Islands from January 28 to February 1, 2006. The towed-diver fish survey team conducted seven surveys around Howland (12 ha) and 10 surveys around Baker (19 ha).

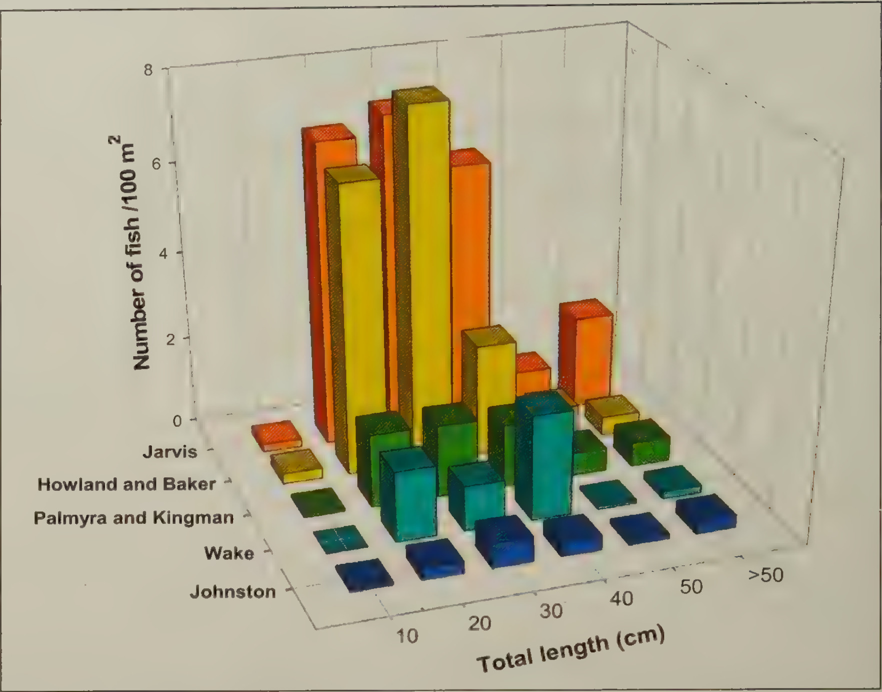


*Figure 11.27. Fish density by size of target families (groupers, snappers, jacks and sharks) as measured on belt transects. Source: PIFSC-CRED, unpub. data.*

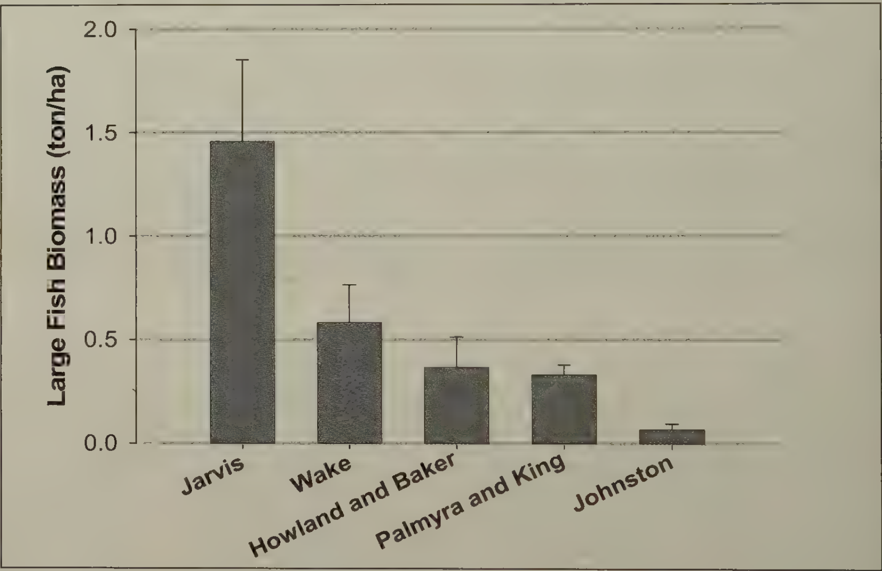


*Figure 11.28. Large fish biomass (>50 cm TL) measured by towed-diver surveys (mean and standard error). Source: PIFSC-CRED, unpub. data.*

Medium-large reef fish biomass at Howland (1.6 ton ha$^{-1}$) was slightly higher than at Baker (1.5 ton ha$^{-1}$). A total of 210 species of coral reef fishes were documented at Howland and Baker Islands by the fish REA team. Damselfishes were represented by 16 species; the fusilier damsel (*Lepidozygous tapeinosoma*) was most abundant and commonly found in large schools. This species, along with two anthiine serranid species, Bartlett's anthias (*Pseudanthias bartlettorum*) and Whitley's splitfin (*Luzonichthys whitleyi*), were observed at all sites. These three species were numerically dominant at both islands. Surgeonfish were common and abundant at all sites at Howland and Baker Islands. Dominant species included the bluespotted bristletooth (*Ctenochaetus marginatus*) the bluelip bristletooth (*C. cyanocheilus*) and the goldrim surgeonfish (*Acanthurus nigricans*). Convict tang (*A. triostegus*) were often observed in large schools, typically at shallower depths above the transects. The most abundant unicornfish was the orange-spine unicornfish (*Naso lituratus*). Wrasses were the most speciose family, with 32 species observed. Numerically, the most abundant wrasse was the blunt-headed wrasse (*Thalassoma amblycephalum*), due to large numbers of new recruits. The humphead wrasse (*Cheilinus undulatus*) was rare. The grey-reef shark (*Carcharhinus amblyrhynchos*) and the whitetip reef shark (*Triaenodon obesus*) were the most abundant sharks recorded. Groupers included large peacock hind (*Cephalopholis argus*), the coral hind (*C. miniata*) and the darkfin hind (*C. urodeta*). The slenderspine grouper (*Gracila albomarginata*) was also common along drop-offs. Snappers were a prominent component of the fish communities at both Howland and Baker Islands. The species most frequently encountered were smalltooth jobfish (*Aphareus furca*), twinspot snapper (*Lutjanus bohar*) and onespot snapper (*L. monostigma*). The most commonly observed angelfishes at both Howland and Baker Islands were the flame angel (*Centropyge loricula*) and the lemonpeel angel (*C. flavissima*). The most prevalent species of triggerfish was the orange-striped triggerfish (*Balistapus undulats*). Parrotfish included six species, of which the most common was the large redlip parrotfish (*Scarus rubroviolaceus*) and the bridled parrotfish (*S. frenatus*). The bigscale soldierfish (*Myripristis berndti*) was the dominant soldierfish. Hawkfishes were common, represented mostlty by the arc-eye hawkfish (*Paracirrhites arcatus*).

Towed-diver surveys of large fish recorded a total of 602 individual fishes at Howland and 269 at Baker. Snappers dominated, the majority of which were the twin-spot snapper (*L. bohar*, n=217). Sharks (Carcharhinids) were the next most numerous family with 166 observations primarily of the grey reef shark (*C. amblyrhynchos*, n=158), 147 of which were observed at Howland; 138 barracuda (*Sphyraena* spp.) were observed at Howland as well. Jacks accounted for 116 observations, 55 of which were black trevally (*Caranx lugubris*), 24 were giant trevally (*C. ignobilis*) and 21 were bluefin trevally (*C. melampygus*). Other notable sightings included schools of scalloped hammerhead shark (*Sphyrna lewini*) and several large humphead wrasse (*C. undulatus*).

*Jarvis Island (2006)*
Fish were resurveyed at Jarvis Island from March 20-22, 2006. Belt transects, SPCs and REA surveys were conducted at nine sites, generally at 13-15 m depth, using the same methodology and sites as in previous years, with one additional site. The towed-diver fish survey team conducted 12 surveys totaling 26 ha around the entire island.

The reefs around Jarvis Island support exceptionally high medium-large fish biomass of reef fishes (9.4 ton ha$^{-1}$), by far the highest of any reefs surveyed by PIFSC-CRED across the Pacific (Figure 11.29). Sharks, groupers, jacks and snappers were common at every REA site surveyed. A total of 165 fish species were recorded by the fish REA divers at Jarvis. Numerically, three fish species dominated the fish fauna at Jarvis; collectively, Bartlett's anthias (*P. bartlettorum*), Whitley's splitfin (*L. whitleyi*) and the fusilier damselfish (*L. tapeinosoma*) made up 60% of all the fish observed. Schools of these three species of small-bodied planktivores were observed at nearly every site with groups sometimes including thousands of individuals. Among larger-bodied fishes, black jacks (*C. lugubris*), spotted hind (*Cephalopholis miniata*), doublebar goatfish (*Parupeneus insularis*) along with several species of surgeonfish including the bluespotted bristletooth (*C. marginatus*), the bluelip bristletooth (*C. cyanocheilus*) and the goldrim surgeonfish (*A. nigricans*) were most abundant. Grey reef sharks (*C. amblyrhynchos*), whitetip reef sharks (*T. obesus*) and manta rays (*Manta birostris*) were also abundant.

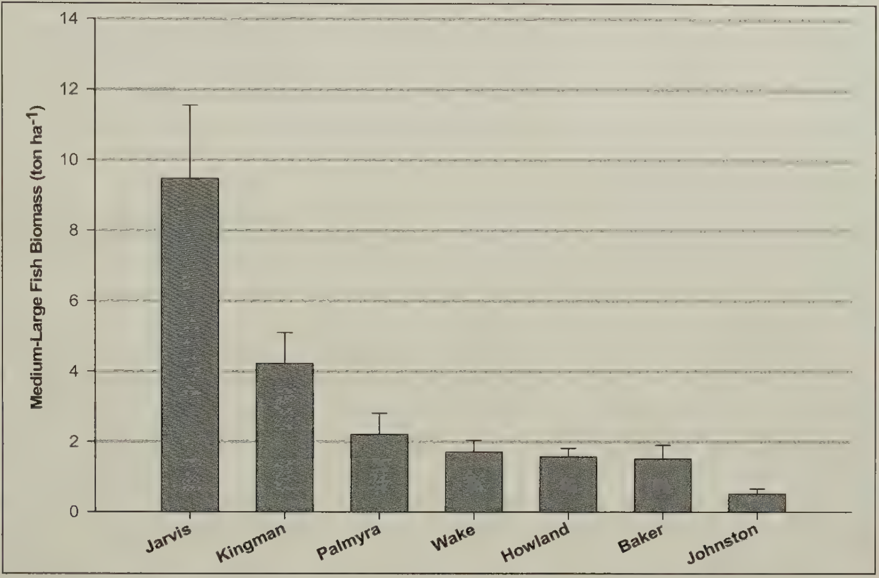


*Figure 11.29. Medium-large fish (TL >25 cm) biomass measured on SPCs. Source: PIFSC-CRED, unpub. data.*

The towed-diver surveys recorded a total of 2,551 fishes at Jarvis. Jacks were the most abundant family with 1,278 sightings, including a large school of 1,000 bigeye trevally (*Caranx sexfasciatus*). Sharks sightings (n=369) were dominated by the grey reef shark (*C. amblyrhynchos*, n=309) with fewer sightings of white tip (*T. obesus*) and black tip reef sharks (*C. melanopterus*). Six scalloped hammerhead (*Sphyrna lewini*) and two great hammerhead sharks (*S. mokarran*) were also seen at Jarvis. Black-margin barracuda (*S. qenie*) were common, with 333 individuals seen primarily in two large assemblages. Other notable observations were nine manta rays (*M. birostris*), two humphead wrasses (*C. undulatus*) and one bumphead parrotfish (*B. muricatum*).

*Johnston Atoll (2006)*
Fish were resurveyed at Johnston Atoll from January 18-23, 2006. Belt transects, SPCs and REA surveys were conducted at 12 previously visited monitoring sites and six newly established sites, using the same methodology as during the previous visit. Most REA sites were inside the lagoon due to challenging sea conditions outside. The towed-diver fish survey team conducted 11 surveys covering 52 ha around the atoll.

Medium-large fish biomass at Johnston Atoll was the lowest of the PRIA, at only 0.5 ton ha$^{-1}$ (Figure 11.29). A total of 120 species of coral reef fishes was documented at Johnston. The bullethead parrotfish (*Chlorurus sordidus*) was seen at every site and was numerically the most abundant parrotfish observed. The palenose parrotfish (*Scarus psitticus*) was also abundant. In sheltered areas the most common species of damselfish were the Hawaiian dascyllus (*Dascyllus albisella*) and the blue-eye damsel (*Plectroglyphidodon johnstonianus*), while at more exposed sites, the dwarf chromis (*Chromis acares*) and agile chromis (*C. agilis*) were common. The diversity and abundance of damselfishes were remarkably low compared to other U.S. Pacific Island surveys. Also lacking were new damselfish recruits. Surgeonfish were common and relatively abundant at Johnston and constituted a major proportion of the fish observed at all sites; the greatest concentrations were found on the outer reef slope. The blue-lined surgeonfish (*Acanthurus nigroris*) was the most common species, followed by goldring surgeonfish (*Ctenochaetus strigosus*) and orange-spine unicornfish (*Naso lituratus*). Wrasses appeared to constitute the most specious family with 17 species. The saddle wrasse (*Thalassoma duperrey*) was recorded at every site and had the highest abundance of the labrids. Hybrids of the saddle wrasse that crossed with the sunset wrasse (*T. lutescens*) and the fivestripe wrasse (*T. quinquevittatum*) were also observed in relatively high numbers. Other species of note included the ringtail wrasse (*Oxycheilinus unifasciatus*) and the sling-jaw wrasse (*Epibulus insidiator*), both of which were present at every site. The belted wrasse (*Stethojulis balteata*) was fairly common and was made up of mostly juveniles. Of the 12 species of butterflyfish, the chevron butterflyfish (*Chaetodon trifascialis*) was the most common and abundant. Other moderately common species included the threadfin butterflyfish (*C. auriga*), the saddleback butterflyfish (*C. epihippium*), and the oval butterflyfish (*C. lunulatus*). Of goatfish, the yellowstripe goatfish (*Mulloidichthys flavolineatus*) was most abundant and was often seen in schools of more than 10. The multibar goatfish (*Parupeneus multifaciatus*) and the doublebar goatfish (*P. insularis*) were also seen frequently. Jacks were common but not abundant at

Johnston Atoll, and the bluefin trevally (*C. melampygus*) was the most numerous species. For snapper, the smalltooth jobfish (*A. furca*) was moderately common. The grey reef shark (*C. amblyrhynchos*) was the only shark observed by the REA fish team at Johnston Atoll, with occasional solitary individuals. Spotted eagle rays (*Aetobatis narinari*) were observed on several occasions, and a single manta ray (*M. birostris*) was observed along the current-swept outside reef.

Towed-diver fish surveys reported the highest large fish density in fore reef habitats. Most common was the bluefin trevally (*C. melampygus*), of which approximately 214 were seen in a large school during a single tow; this group may have constituted a spawning aggregation. The second most common large fish species was the grey reef shark (*C. amblyrhynchos*; 67 individuals). Other notable fish included 22 cornetfish (*Fistularia commersonii*), 12 redlipped parrotfish (*Scarus rubroviolaceus*), 12 green jobfish (*Aprion virescens*) and schools of black trevally (*C. lugubris*).

*Palmyra Atoll and Kingman Reef 2006*

Fish were resurveyed at Palmyra and Kingman reefs from March 23 to April, 3 2006. Belt transects, SPCs and REA surveys were conducted at 13 (Palmyra) and 16 (Kingman) previously visited monitoring sites. Towed-diver fish surveys included 18 surveys totaling 42 ha around Palmyra Atoll and 22 surveys totaling 50 ha around Kingman Reef.

Medium-large fish biomass around Palmyra (2.2 ton $ha^{-1}$) made up only half of the biomass found at Kingman but was still very high compared to other regions of the U.S. Pacific (Figure 11.29). Collectively 176 species of reef fishes were recorded at Palmyra. The three schooling planktivores that dominated the numbers of fish at Jarvis Island were not nearly as abundant at Palmyra. The most abundant species on belt transects were dwarf chromis (*Chromis acares*), Vanderbilt's chromis (*C. vanderbilti*) and bicolor chromis (*C. margaritifer*). Diversity was highest among wrasses (35 species recorded) and surgeonfish/unicornfish (25 species). Large fish, including sharks, were generally less abundant at Palmyra than at Jarvis with the exception of the twinspot snapper (*L. bohar*). Humphead wrasses (*C. undulatus*) and manta rays (*M. birostris*) were encountered commonly, but rarely passed within the quantitative boundaries of the surveys.

The most abundant large (TL >50cm) fish sighted on towed-diver surveys around Palmyra was the twinspot snapper (*L. bohar*, 444 individuals). The second most abundant species was the Pacific steephead parrotfish (*Chlorurus microrhinos*, 61 individuals), followed by grey reef shark (*C. amblyrhynchos*; 58 individuals). The giant trevally (*C. ignobilis*) was also common at Palmyra (29 sightings). Other notable observations included two bumphead parrotfish (*B. muricatum*) and 18 humphead wrasse (*C. undulatus*).

Kingman Reef includes several habitat types not found at Jarvis and Palmyra. Kingman is a submerged atoll that consists of exposed outer reef, extensive back reef, a series of small, scattered pinnacles and a submerged western atoll rim. Fish surveys were conducted at one or more sites within each of these habitat types. Medium-large fish biomass was particularly high at Kingman Reef (4.2 ton $ha^{-1}$; Figure 11.29), which represents the second highest value in the PRIA. Numerically, damselfish (family Pomacentridae) dominated, although species composition varied greatly around the atoll. Surgeonfish (family Acanthuridae) were also very abundant at most sites. Among larger-bodied fishes surveyed, twinspot snapper (*L. bohar*) were abundant at all sites. Large aggregations of yellowback fusiliers (*Caesio teres*), blackfin barracuda (*Sphyraena qenie*) and rainbow runner (*Elagatis bipinnulata*) were observed at scattered sites. Sharks appeared to be more abundant at Kingman than at Palmyra, but less abundant than at Jarvis. No humphead wrasse or bumphead parrotfish were observed by the fish REA team at Kingman.

The most abundant species observed on towed-diver surveys at Kingman was the twinspot snapper (*L. bohar*) with 477 individuals. The Pacific steephead parrotfish (*C. microrhinos*; 260 individuals) was the second most frequently observed large fish. These were followed by the grey reef shark (*C. amblyrhyncos*; 93 individuals), and the whitetip reef shark (*T. obesus*; 47 individuals). Another notable fish sighting at Kingman was the giant grouper (*Epinephelus lanceolatus*).

*Wake Atoll (2005, 2007)*

Fish were surveyed for the first time by PIFSC-CRED at Wake Atoll from October 18 to 22, 2005, and again from April 30 to May 3, 2007. Belt transects, SPCs and REA surveys were conducted at 13 newly established sites with the same methodology used elsewhere in the U.S. Pacific Islands. The towed-diver fish survey team conducted 19 surveys, around the atoll totaling 40 and 44 ha, respectively, during the two visits to the atoll.

In general, Wake appeared to support healthy populations of fish that are typically more depleted in other areas that are exposed to fishing and other human activities. Observations in both survey years were generally consistent. Medium-large fish biomass was around 1.7 ton $ha^{-1}$, which is slightly below the average for the PRIA (Figure 11.29). Further, large, potentially wary species were easily approached by divers. A total of 190 species of coral reef fishes were documented at Wake. Parrotfish were the most common medium-large fish, and were commonly found in schools of up to 100 that included many very large individuals. The tan-faced parrotfish (*Chlorurus frontalis*) and rainbow parrotfish (*Scarus forsteni*) dominated. The large bumphead parrotfish (*B. muricatum*), very rare in most other areas of the U.S. Pacific, was encountered on nearly every dive, occasionally in schools of up to 30 individuals. Also common in both years were humphead wrasse (*C. undulatus*) and several species of commercially exploited grouper. Other common medium-large fish included jacks (primarily two large schools of *C. sexfasciatus*) and a consistent presence of bluefin trevally (*C. melampygus*). Gray reef sharks (*C. amblyrhynchos*) were occasionally seen, as was one tiger shark (*Galeocerdo cuvier*).

Most sites exhibited a high degree of similarity in terms of fish species composition. There also seemed to be little change with depth to about 20 m, the depth limit of the REA surveys. Few deep water species were observed along the steep outer reef drop-offs. Circulation in the lagoon at Wake was significantly altered by the construction of a causeway. Only one survey dive was conducted in the near-zero visibility lagoon; fish fauna was patchily distributed on patch reefs smaller than the length of the transect lines. Based on previous checklists by Lobel and Lobel (2004) and the USFWS and NMFS (1999), new records were likely found at Wake for the following 10 species: black-spotted puffer (*Arothron nigropunctatus*), stareye parrotfish (*Calotomus carolinus*), multi-barred angelfish (*Centropyge multifasciata*), tiger shark (*G. cuvier*), blackear wrasse (*Halichoeres melasmopomus*), wedge-tailed wrasse (*Labropsis xanthonota*), whitemargin unicornfish (*Naso annulatus*), redtooth triggerfish (*Odonus niger*), bridled parrotfish (*Scarus frenatus*) and bigeye scad (*Selar crumenophthalmus*). A possible new species of wrasse (*Pseudojuloides* sp. B) was also observed and collected.

The most notable observation of the towed-diver large fish surveys at Wake was the abundance of bumphead parrotfish (*B. muricatum*; 68 sightings). The humphead wrasse (*C. undulatus*; 90 sightings) was also common in both years. Another notable observation was the high abundance of spotted eagle rays (*A. narinari*; 27 sightings). The most numerically abundant fish, however, was bigeye jacks (*C. sexfasciatus*), which were observed in schools of up to 1,200 individuals with approximately 70% over 50 cm TL. A large school of milkfish (*Chanos chanos*, about 200-250 fish) was also seen. Grey reef sharks (*C. amblyrhynchos*) were among the top three most abundant species on towed-diver surveys. Parrotfish of several species, as well as planktivorous unicornfish were abundant (particularly *Naso brevirostris*), though only a few were of sufficient size (>50 cm TL) to be recorded during towed-diver surveys.

### Marine Mammals

Marine mammals are regularly monitored by the USFWS at Palmyra Atoll. In summer 2006, a mesoplodon whale carcass washed ashore in the east lagoon, which was the third dead beaked whale stranding on Palmyra Atoll NWR in one year. Preliminary results indicate that these whales are potentially a new and undescribed species of beaked whales. Two sightings of a large (7-10 m) brown or tan beaked whale were reported at Kingman Reef in August and September 2007. Further observations or photos of the whale were not possible (J. Maragos, pers. obs.).

### Marine Macroinvertebrates

Towed-diver benthic surveys were conducted in shallow water habitats around all of the PRIA, and divers recorded habitat composition and character and enumerated conspicuous macroinvertebrates. Molluscs, echinoderms, and holothuroids were tallied, specifically the giant clam, *Tridacna* spp., COTS, and all urchins and sea cucumbers. (Figure 11.30). The Line and Phoenix Islands were surveyed in 2006 aboard the NOAA ship *Hi'ialakai*. The overall lack of macroinvertebrate fauna throughout the fore reef habitats at Palmyra Atoll is of specific interest, as is the high concentration, but patchy distribution of COTS at Kingman Reef. In addition, Kingman Reef exhibited an overall high abundance and diversity of macroinvertebrates and the highest concentration of giant clams in the PRIA. Jarvis Island had an overall low concentration of macroinvertebrates, with the most abundant and diverse values recorded at sites on the western side of the island. Johnston Atoll has the second highest concentration of COTS in the PRIA; over 60% of observed COTS were found on the fore reef. No COTS were observed at either Howland or Baker. Low densities of both urchins and giant clams were observed at both islands as well.

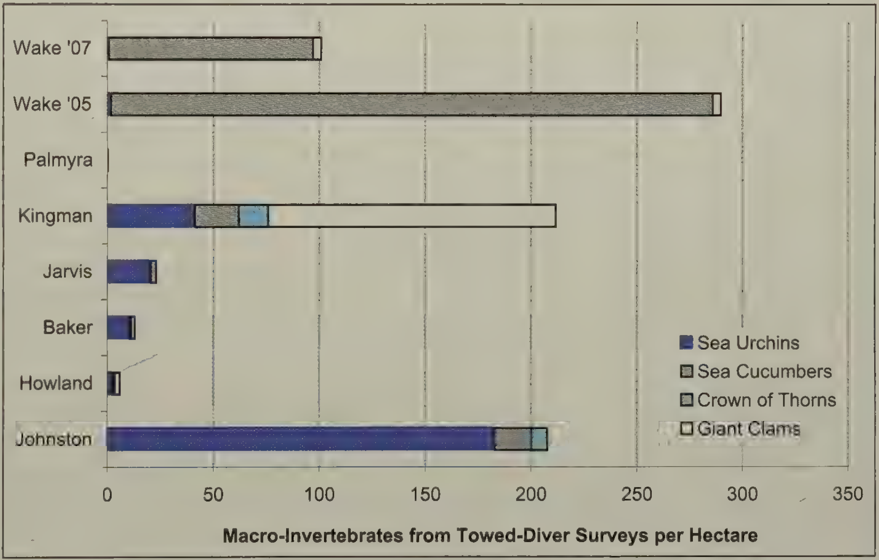


*Figure 11.30. Macroinvertebrates from towed-diver surveys per hectare. Source: PIFSC-CRED, unpub. data.*

Wake Atoll was surveyed by towed divers in 2005 and 2007. Surprisingly, only a single COTS was recorded during all surveys for both years around Wake Atoll. The most abundant macroinvertebrates observed around Wake were sea cucumbers; an average of approximately 7,000 was recorded along the southern coastline during the two survey periods (Figure11.31).

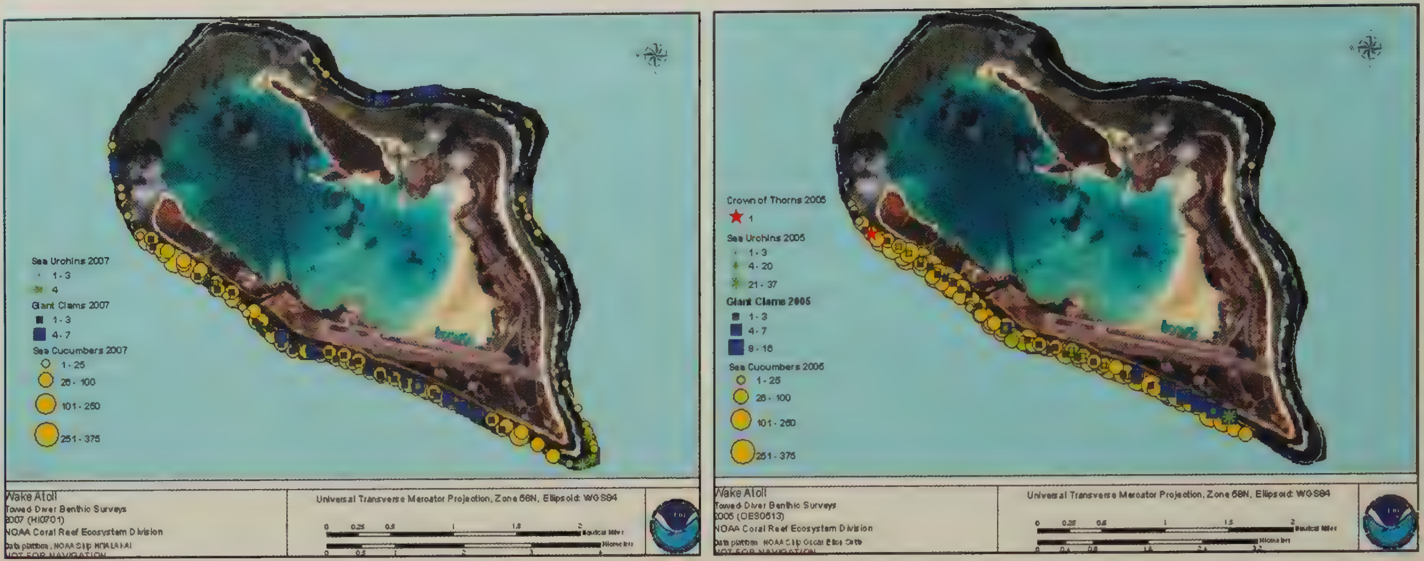

Sea Urchins 2007
1 - 3
4
Giant Clams 2007
1 - 3
4 - 7
Sea Cucumbers 2007
1 - 25
26 - 100
101 - 250
251 - 375
Wake Atoll
Towed Diver Benthic Surveys
2007 (HI0701)
NOAA Coral Reef Ecosystem Division
Data platform , NOAA Ship HI'IALAKAI
NOT FOR NAVIGATION
Universal Transverse Mercator Projection, Zone 58N, Ellipsoid: WGS84
Crown of Thorns 2005
1
Sea Urchins 2005
1 - 3
4 - 20
21 - 37
Giant Clams 2005
1 - 3
4 - 7
8 - 16
Sea Cucumbers 2005
1 - 25
26 - 100
101 - 250
251 - 375
Wake Atoll
Towed Diver Benthic Surveys
2005 (OES0513)
NOAA Coral Reef Ecosystem Division
NOT FOR NAVIGATION
Universal Transverse Mercator Projection, Zone 58N, Ellipsoid: WGS84

*Figure 11.31. Distribution of estimated population densities of COTS, giant clams, sea cucumbers and sea urchins around Wake Atoll from towed-diver benthic surveys completed in 2005 and 2007. Source: PIFSC-CRED, unpub. data.*

## CURRENT CONSERVATION MANAGEMENT ACTIVITIES

The USFWS and NOAA will continue to collaborate on biennial research expeditions to Johnston, Kingman, Palmyra, Baker, Howland and Jarvis Islands. Research expeditions to Wake Island are conducted under NOAA sponsorship with permission and assistance from the DOI and the U.S. Air Force.

### World Heritage and Ramsar Conventions

In 2002, the United Nations Education, Scientific, and Cultural Organization (UNESCO) held an international marine World Heritage workshop in Hanoi, Vietnam. The workshop was attended by nearly 100 marine experts who were charged with developing a list of priority areas for World Heritage (WH) status. The paucity of WH sites in the Pacific Ocean was particularly highlighted and the Line and Phoenix Islands were two of 16 Pacific areas proposed for WH evaluation. Subsequently, additional workshops were held in Kiritimati (Christmas Island, Republic of Kiribati); Durban, South Africa; and Honolulu, Hawaii, in 2003, 2005 and 2007, respectively, to enlist the support and participation of the U.S., Republic of Kiribati, the Cook Islands and French Polynesia as part of a broader "Central Pacific WH Project" focusing on the low reef islands and atolls in the region. Five of the PRIA (Baker, Howland, Jarvis, Kingman and Palmyra NWR) and Rose Atoll NWR were proposed for tentative listing and nomination as a serial site for World Heritage by the U.S. Assistant Secretary of Interior for Fish and Wildlife and Parks on March 4, 2005. Johnston Atoll NWR was not added to this list because of ongoing negotiations between the Departments of Interior and Defense on the future status of the atoll. Unfortunately, the U.S. Tentative List was closed for additions at that time and further action was suspended. Although the Tentative List was eventually reopened in early 2007 for three months, and despite the support of TNC and the Governor of American Samoa, the application for the five PRIA and Rose Atoll could not be processed and reviewed in time to meet the deadline for submissions. All six areas are now being evaluated as Ramsar (1971 Convention on Wetlands of International Importance at Ramsar, Iran) sites by DOI and UNESCO. Meanwhile the Republic of Kiribati created the Phoenix Island Protected Area that covers over 400,000 km$^2$ in February 2008 and is nominating all eight of its Phoenix Islands for World Heritage status. If this latter initiative succeeds, it may be possible to add the U.S. PRIA via more streamlined procedures as part of a trans-boundary nomination.

## OVERALL CONCLUSIONS AND RECOMMENDATIONS

Cooperative biennial Pacific RAMP surveys should continue at these remote islands in order to: 1) improve the scientific understanding of these ecosystems as a basis for sound management; 2) improve and extend monitoring of spatial and temporal changes at multiple depths at the same sites and within additional habitats in these ecosystems in response to natural and anthropogenic forces; 3) collaborate more closely with other research institutions in the region; 4) help elucidate associations between fish (a primary resource) and other components of the coral reef ecosystem; and 5) assist the USFWS, TNC, NMFS and other resource managers in efforts to improve the scientific basis for protecting the coral reef ecosystems and the associated fish and wildlife resources in the PRIA.

Although the PRIA are in excellent condition as a whole (Figure 11.32), stressed areas need further examination to determine whether additional remediation or restoration is warranted. The following is a list of the priority areas for future monitoring:

- Northwest boat landing area at Baker Island that is likely stressed from dissolved iron
- Other historic boat landings at Howland and Jarvis
- Ship grounding sites including the two at Kingman and Palmyra to assist future efforts to remove the debris
- Sites where the invasive corallimorph *Rhodactis howesii* is established
- Evaluate and possibly deploy remotely placed sensors and other remote satellite surveillance technology to discourage unauthorized visitors and fishers
- Expand the REA and permanent transect monitoring to multiple depths and habitats
- Assist or collaborate in special studies to assess and evaluate possible restoration options for Palmyra's lagoon
- Continue evaluating the decline of coral communities in Johnston and Wake lagoons

*Figure 11.32. The coral reef ecosystem resources in the PRIA are generally in excellent condition. Photo: PIFSC-CRED.*

It is recommended that all six PRIA covered in this chapter (along with Rose Atoll NWR) should eventually be added to the U.S. Tentative List and nominated as a single serial candidate for World Heritage status or added as part of an inscribed World Heritage property.

## REFERENCES

Brainard R., J. Maragos, R. Schroeder, J. Kenyon., P. Vroom, S. Godwin, R. Hoeke, G. Aeby, R. Moffit, M. Lammers, J. Gove, M. Timmers, S. Holzwarth, and S. Kolinski. 2005. The State of Coral Reef Ecosystems of the U.S. Pacific Remote Island Areas. pp. 338-372. In: J.E. Waddell (ed.). The State of the Coral Reef Ecosystems of the United States and Pacific Freely Associated States: 2005. NOAA Technical Memorandum NOS NCCOS 11. Silver Spring, MD. 522 pp.

Brainard, R., J. Asher, J. Gove, J. Heyler, J. Kenyon, F. Mancini, J. Miller, S. Myhre, M. Nadon, J. Rooney, R. Schroeder, E. Smith, B. Vargas-Angel, S. Vogt, and P. Vroom. In press. Coral Reef Ecosystem Monitoring Report for American Samoa: 2002-2006. NOAA Special Report NMFS PIFSC. Honolulu, HI.

Bythell, J., O. Pantos, and L. Richardson. 2004. White plague, white band, and other “white diseases”. pp. 351-365. In: E. Rosenberg and Y. Loya (eds.). Coral Health and Disease. Springer. Berlin, Heidelberg, New York. 488 pp.

Clouard, V. and A. Beonneville. 2005. Ages of seamounts, islands, and plateaus on the Pacific Plate. pp. 71-90. In: G. Foulger, J. Natland, D. Presnall, and D.L. Anderson (eds.). Plates, Plumes and Paradigms. Geological Society of America Special Volume 388. 898 pp.

Davis, A.S., L.B. Gray, D.A. Clague, and J.R. Hein. 2002. The Line Islands revisited: New 40Ar/39Ar geochronologic evidence for episodes of volcanism due to lithospheric extension. Electronic Article. Geochemistry, Geophysics, Geosystems 3(3) 1018. http://www.agu.org/journals/gc/gc0203/2001GC000190/2001GC000190.pdf.

Emery, K.O. 1956. Marine geology of Johnston Islands and its surrounding shallows, Central Pacific Ocean. Geol. Soc. Am. Bull. 67: 1505-1519.

Ferguson, S., C. Musburger, P. Ayotte, T. Wass, B. Vargas-Angel, J. Maragos, S. Godwin, A. Tribollet, B. DeJosepth, A. Hall, M. Timmers, E. Coccagna, E. Dobbs, K. Hogrefe, D. Merritt, C. Young, K. Lino, E. Lundblad, J. Jones, J. Weiss, S. Charette, and J. Bostick. 2006. Hi’ialakai Cruise Report HI-06-04. Coral Reef Ecosystem Division, Pacific Islands Fisheries Science Center, National Marine Fisheries Service, NOAA. http://www.pifsc.noaa.gov/library/hiialakai.php.

Ferguson, S., B. Zgliczynski, M. Nadon, P. Brown, J. Kenyon, B. Vargas-Angel, E. Keenan, R. Tomasetti, B. DeJoseph, J. Helyer, B. Richards, S. Charette, A. Hall, J. Asher, N. Pomeroy, F. Mancini, O. Vetter, J. Bostick, H. Wang, and J. Miller. 2007. Hi’ialakai Cruise Report HI-07-01 Cruise Report. Coral Reef Ecosystem Division, Pacific Islands Fisheries Science Center, National Marine Fisheries Service, NOAA. http://www.pifsc.noaa.gov/library/hiialakai.php.

Firing, E., R. Lukas, J. Sadler, and K. Wyrtki. 1983. Equatorial Undercurrent disappears during 1982-1983 El Niño. Science 222(4628): 1121-1123.

Friedlander A., G. Aeby, R. Brainard, A. Clark, E. DeMartini, S. Godwin, J. Kenyon, R. Kosaki, J. Maragos, and P. Vroom. 2005. The State of the Coral Reef Ecosystems of the Northwestern Hawaiian Islands. pp. 270–311. In: J.E. Waddell (ed.). The State of the Coral Reef Ecosystems of the United States and Pacific Freely Associated States: 2005. NOAA Technical Memorandum NOS NCCOS 11. Silver Spring, MD. 522 pp.

Gove, J.M., M.A. Merrifield, and R.E. Brainard. 2006. Temporal variability of current-driven upwelling at Jarvis Island. Electronic Article. J. Geophys. Res. 111(C12011). http://www.agu.org/journals/jc/jc0612/2005JC003161/2005JC003161.pdf.

Hendry, R. and C. Wunsch. 1973. High Reynolds number flow past an equatorial island. J. Flu. Mech. 58: 97-114.

Hoegh-Guldberg, O. 1999. Climate change, coral bleaching and the future of the world’s coral reefs. Mar. Freshw. Res. 50(8): 839-866.

Hughes, T.P., A.H. Baird, D.R. Bellwood, M. Card, S.R. Connolly, C. Folke , R. Grosberg, O. Hoegh-Guldberg, J.B.C. Jackson, J. Kleypas, J.M. Lough, P. Marshall, M. Nystrom, S.R. Palumbi, J.M. Pandolfi, B. Rosen, and J. Roughgarden. 2003. Climate Change, Human Impacts, and the Resilience of Coral Reefs. Science 301(5635): 929-933.

Intergovernmental Panel on Climate Change (IPCC). 2007. The Physical Science Basis, Summary for Policy Makers, Contribution of Working Group ! to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor, and H.L. Miller (eds.). Cambridge University Press. Cambridge, UK and New York, NY. 21 pp. http://ipcc-wg1.ucar.edu/wg1/Report/AR4WG1_Print_SPM.pdf.

Keating, B.H. 1987. Structural Failure and Drowning of Johnston Atoll, Central Pacific Basin. pp. 49-59. In: B.H. Keating, P. Fryer, R. Batiza, and G.W. Boehlert (eds.). Seamounts, Islands, and Atolls Geophysical Monograph 43. American Geophysical Union. Washington, DC. 207 pp.

Kleypas, J.A., R.W. Buddemeier, D. Archer, J. Gattuso, C. Langdon, and B.N. Opdyke. 1999. Geochemical Consequences of Increased Atmospheric Carbon Dioxide on Coral Reefs. Science 284(5411): 118-120.

Kleypas, J.A., R.A. Feely, V.J. Fabry, C. Langdon, C.L. Sabine, and L.L.Robbins. 2006. Impacts of Ocean Acidification on Coral Reefs and Other Marine Calcifiers: A Guide for Future Research. Report of a workshop by National Science Foundation, NOAA, US Geological Survey. St. Petersburg, FL. 96 pp. http://www.ucar.edu/communications/Final_acidification.pdf.

Koppers, A.A.P. and H. Staudigel. 2007. Asynchronous Bends in Pacific Seamount Trails: A Case for Extensional Volcanism? Science 307(5711): 904-907.

Lobel, P.S. and L.K. Lobel. 2004. Annotated checklist of the fishes of Wake Atoll. Pac. Sci. 58(1): 65-90.

Littler, M.M. and D.S. Littler. 1998. An undescribed fungal pathogen of reef-building crustose coralline algae discovered in American Samoa. Coral Reefs 17(2): 144.

Littler, D.S. and M.M. Littler. 2003. South Pacific reef plants: a diver's guide to the plant life of South Pacific coral reefs. Off-set Graphics Inc. Washington, DC. 331 pp.

Maragos, J.E. 1994. Description of reefs and corals for the 1988 protected area survey of the Northern Marshall Islands. Atoll Res. Bull. 419: 1-106.

Maragos, J.E. and P.L. Jokiel. 1986. Reef corals of Johnston Atoll: One of the world's most isolated reefs. Coral Reefs 4: 141-150.

Maragos, J., D. Potts, G. Aeby, D. Gulko, J. Kenyon, D. Siciliano, and D. VanRavenswaay. 2004. 2000-2002 rapid ecological assessment of corals on the shallow reefs of the Northwestern Hawaiian Islands. Part 1: Species and distribution. Pac. Sci. 58(2): 211-230.

Maragos, J., A. Friedlander, S. Godwin, C. Musburger, E. Flint, O. Pantos, E. Sala, and S. Sandin. In press. US coral reefs in the Line and Phoenix Islands, Central Pacific Ocean: Status, Threats and Significance. pp. 639-650. In: Riegl B. and Dodge R.E. (eds) Coral Reefs of the USA. Coral Reefs of the World, Volume 1. Springer. 806 pp.

Maragos, J., J. Miller, J. Gove, E. DeMartini, A. Friedlander, S. Godwin, C. Musburger, M. Timmers, R. Tsuda, P. Vroom, E. Flint, E. Lundblad, J. Weiss, P.Avotte, E. Sala, S. Sandin, S. McTee, T. Wass, D. Siciliano, R. Brainard, D. Obura, S. Ferguson, and B. Mundy. In Press. US coral reefs in the Line and Phoenix Islands, Central Pacific Ocean: History, Geology, Oceanography, and Biology. pp. 591-638. In: B. Riegl and R.E. Dodge (eds.). Coral Reefs of the USA. Coral Reefs of the World, Volume 1. Springer. 806 pp.

McPhaden, M., A. Busalacchi, R. Cheney, J. Donguy, K. Gage, D. Halpern, M. Ji, P. Julian, G. Meyers, G. Mitchum, P. Niiler, J. Picaut, R. Reynolds, N. Smith, and K. Takeuchi. 1998. The Tropical Ocean-Global Atmosphere observing system: A decade of progress. J. Geophys. Res. 103(C7): 14, 169-240.

NODC/SOG. 2006. 4 km Pathfinder Version 5.0 User Guide. Satellite Oceanography Group, National Oceanographic Data Center (NDOC), NOAA Satellite and Information Service (NEDSIS). http://www.nodc.noaa.gov/sog/pathfinder4km/userguide.html

Orr, J.C., V.J. Fabry, O. Aumont, L. Bopp, S.C. Doney, R.A. Feely, A. Gnanadesikan, N. Gruber, A. Ishida, F. Joss, R.M. Key, K. Lindsay, E. Maier-Reimer, R. Matear, P. Monfray, A. Mouchet, R.G. Najjar, G. Plattner, K.B. Rodgers, C.L. Sabine, J.L. Sarmiento, R. Schlitzer, R.D. Slater, I.J. Totterdell, W. Weirig, Y. Yamanaka, and A. Yool. 2005. Anthropogenic Ocean Acidification over the Twenty-First Century and its Impact on Calcifying Organisms. Nature 437: 681-686.

Philander, S. 1990. El Niño, La Niña and the Southern Oscillation. Academic Press, New York. 293 pp.

Preskitt, L.B., P.S. Vroom, and C.M. Smith. 2004. A rapid ecological assessment (REA) quantitative survey method for benthic algae using photo quadrats with SCUBA. Pac. Sci. 58: 201-209.

Roemmich, D. 1984. Indirect sensing of equatorial Currents by means of island pressure measurements. J. Phys. Oceanogr. 14: 1458-1469.

Schroeder, R., C. Musburger, P. Ayotte, T. Wass, D. Fenner, B. Vargas-Angel, J. Kenyon, J. Maragos, H. Bolick, N. Daschbach, M. Dailer, A. Tribollet, S. Holzwarth, B. Richards, S. Charette, A. Hall, E. Coccagna, E. Keenan, E. Dobbs, R. Hoeke, J. Gove, K. Hogrefe, K. Fagan, K. Wong, S. Ferguson, J. Jones, E. Lundblad, J. Smith, J. Bostick, F. Le'iato, and D. Tuamoheloa. 2006. Hi'ialakai Cruise Report HI-06-02. Coral Reef Ecosystem Division, Pacific Islands Fisheries Science Center, National Marine Fisheries Service, NOAA. http://www.pifsc.noaa.gov/library/hiialakai.php

Smith, W.H.F. and D.T. Sandwell, 1997. Global Sea Floor Topography from Satellite Altimetry and Ship Depth Soundings. Science 277(5334): 1956-1962.

Smith, W.M. 2006. Palmyra Atoll National Wildlife Refuge May-September 2006: Activity Report. U.S. Fish and Wildlife Report. 16 pp.

Sweistac, S. U.S. Missile Defense Agency. Washington, DC. Personal communication.

Timmers, M., S. Holzwarth, J. Asher, E. Keenan, J. Gove, R. Hoeke, D. Merritt, K. Hogrefe , K. Page, A. Tribollet, J. Kenyon, V. Bonito, J. Laughlin, C. Musburger, J. Grover, W. Gordon, and P. White. 2006. Oscar Elton Sette Cruise Report OES-05-13. Coral Reef Ecosystem Division, Pacific Islands Fisheries Science Center, National Marine Fisheries Service, NOAA. http://www.pifsc.noaa.gov/library/oscarsette.php

Trenberth, K.E. 1997. The Definition of El Niño. Bull. Am. Meteorol. Soc. 78(12): 2771-2777.

Tsuda, R.T., I.A. Abbott, and K.B. Foster. 2006. Marine benthic algae from Wake Atoll. Micronesica 38: 207-219.

Tsuda, R.T., P.S. Vroom, I.A. Abbott, J.R. Fisher, and K.B. Foster. In review. Additional marine benthic algae from Howland Island and Baker Island, Central Pacific. Pac. Sci.

Turgeon, D.D., R.G. Asch, B.D. Causey, R.E. Dodge, W. Jaap, K. Banks, J. Delaney, B.D. Keller, R. Speiler, C.A. Mato, J.R. Garcia, E. Diaz, D. Catanzaro, C.S. Rogers, Z. Hillis-Starr, R.S. Nemeth, M. Taylor, G.P. Schmahl, M.W. Miller, D.A. Gulko, J.E. Maragos, A. Friedlander, C.L. Hunter, R.S. Brainard, R. Craig, R.H. Richmond, G. Davis, J. Starmer, M. Trianni, R. Houk, C.E. Birkeland, A. Edward, Y. Golbuu, J. Gutierrez, N. Idechong, G. Paulay, A. Tafileichig, and N.V. Velde. 2002. The State of Coral Reef Ecosystems of the United States and Pacific Freely Associated States: 2002. NOAA/NOS/NCCOS. Silver Spring, MD. 265 pp.

U.S. Fish and Wildlife Service and National Marine Fisheries Service. 1999. Baseline marine biological survey: Peacock Point outfall and other point-source discharges: Wake Atoll, Pacific Ocean. Report prepared for the Department of the Army, U.S. Army Space and Missle Defence Command. Prepared by USDOI Fish and Wildlife Service and NOAA National Marine Fisheries Service. Honolulu, HI. 23 pp. http://www.mda.mil/mdaLink/pdf/wakelc_10_99.pdf.

Vroom, P.S., M. Dailer, M. Timmers, J. Maragos, B. Vargas-Angel, C. Musburger, P. Ayotte, S. McTee, B. Richards, E. Keenan, S. Charette, A. Hall, J. Gove, K. Hogrefe, R. Hoeke, J. Jones, J. Miller, J. Chojnacki, L. Woodward, C. Eggleston, S. Cooper Alletto, and R. Heikkenin. 2006. Hi'ialakai Cruise Report HI-06-01. Coral Reef Ecosystem Division, Pacific Islands Fisheries Science Center, NOAA National Marine Fisheries Service. http://www.pifsc.noaa.gov/library/hiialakai.php.

Vroom, P.S., K.N. Page, J.C. Kenyon, R.E. Brainard. 2006. Algae-Dominated Reefs. Am. Sci. 94: 430-437.

Vroom, P.S., C.A. Musburger, S. Cooper Alletto, J.E. Maragos, K.N. Page, M.A.V. Timmers. In preparation. Benthic and fish community assemblages reveal differences between geographically close equatorial islands. Coral Reefs.

Willis, B., C. Page, and E. Dinsdale. 2004. Coral disease on the Great Barrier Reef. pp. 69-104. In: E. Rosenberg and Y. Loya (eds.). Coral Health and Disease. Springer. Berlin, Heidelberg, New York. 488 pp.

Work, T., S. Coles, and R. Rameyer 2001. Johnston Atoll reef health survey. National Wildlife Health Center, Honolulu Field Station, U.S. Geological Survey. Honolulu, HI. 28 pp.

Work, T.M. and G.S. Aeby. 2007. Final report on invasive corallimorph at Palmyra NWR. U.S. Geological Survey, National Wildlife Health Center and University of Hawaii Institute of Marine Biology. Kaneohe, HI. 16 pp.

Yu, X. and M. McPhaden. 1999. Seasonal Variability in the Equatorial Pacific. J. Phys. Oceanogr. 29: 925-947.

# The State of Coral Reef Ecosystems of the Republic of the Marshall Islands

Maria Beger[1], Dean Jacobson[2], Silvia Pinca[3], Zoe Richards[4], Don Hess[2], Frankie Harriss[2], Cathie Page[4], Eric Peterson[5] and Nicole Baker[6]

## INTRODUCTION AND SETTING

Located in the central Pacific Ocean and spanning more than 5,025,000 km$^2$ (1,940,000 mi$^2$), the Republic of the Marshall Islands (RMI) is comprised of 1,225 islands and islets including 29 atolls and five solitary, low coral islands. Only 0.01%, or 181.3 km$^2$, of the country is dry land. The atolls and islands are arranged in two roughly parallel groupings—the eastern Ratak (or Sunrise) Chain containing 15 atolls and two islands, and the Ralik (Sunset) Chain to the west containing 14 atolls and three islands (Figure 12.1).

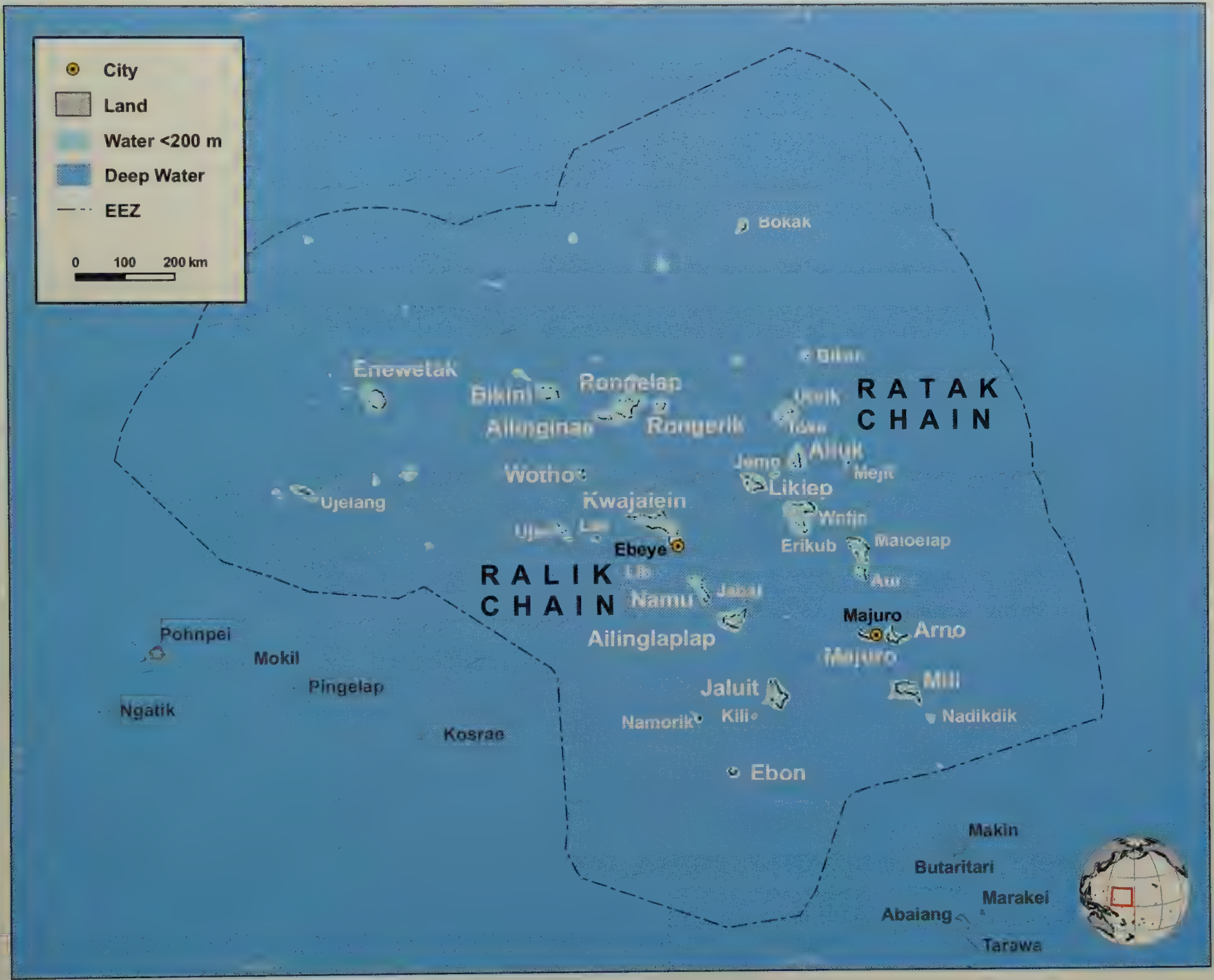

City
Land
Water <200 m
Deep Water
EEZ
0
100
200 km
Bokak
Bikar
Enewetak
Bikini
Rongelap
Ailinginae
Rongerik
Utirik
Taka
RATAK CHAIN
Jemo
Ailuk
Mejit
Wotho
Likiep
Ujelang
Kwajalein
Ujae
Lae
Wotje
Ebeye
Erikub
Maloelap
RALIK CHAIN
Lib
Aur
Namu
Jabat
Majuro
Arno
Ailinglaplap
Majuro
Pohnpei
Mokil
Pingelap
Ngatik
Kosrae
Jaluit
Mili
Namorik
Kili
Nadikdik
Ebon
Makin
Butaritari
Marakei
Abaiang
Tarawa

*Figure 12.1. Locator map of the RMI. Map: K. Buja.*

The RMI formed when fringing reefs began to establish and grow around emergent volcanoes. While the ancient volcanic peaks gradually sank and shrank, the fringing reefs continued to grow and eventually coral atolls formed after the volcanoes disappeared entirely beneath the sea. The five solitary islands of the RMI were formed in much the same way, but the peaks were small enough that no interior lagoon developed. Most atolls of the Marshall Islands consist of an irregular shaped reef-rim with numerous islets encircling a lagoon with water depths that can reach 60 m. The islets are more prevalent on the windward side. The atolls vary in size from Kwajalein, the world's largest atoll with 16.4 km$^2$ of dry land

---

1. The Ecology Centre and The Commonwealth Research Facility for Applied Environmental Decision Analysis, The University of Queensland
2. College of the Marshall Islands
3. Secretariat of the Pacific Community
4. ARC Centre of Excellence for Reef Studies, School of Marine and Tropical Biology and Comparative Genomics Centre, James Cook University
5. School of Architectural, Civil and Mechanical Engineering, Victoria University
6. Independent consultant based in Victoria, Australia

and a lagoon of 2,174 km$^2$, to Bikar with 0.5 km$^2$ of land and 37.4 km$^2$ of lagoon, and Namdrik with 2.7 km$^2$ of land and 8.4 km$^2$ of lagoon. Individual islands range from tiny sand-spits and vegetated islets that are inundated during storms and extreme high tides to much larger islands such as Kaben Island at Maloelap Atoll, and Wotho Island at Wotho Atoll, both of which are over 8 km$^2$. Lagoons within the atolls typically have at least one natural reef pass that provides boat access; however, some, such as Namdrik Atoll, have no natural passes.

Prior to Western contact, the people of the Marshall Islands relied on fishing and tropical agriculture for subsistence. In this environment, the Marshallese developed world-renowned seafaring skills, which included the design of ocean-going canoes and the creation of a complex navigation system based on stars, swell, currents and wave refraction patterns. The culture and skills that evolved allowed the Marshallese to thrive in the widely dispersed islands. The present population of approximately 61,815 is concentrated in the urban areas of Majuro and Ebeye (Kwajalein Atoll), home to approximately two-thirds of the population (CIA, 2008). The remaining one-third lives in the more remote atolls, commonly known as the “outer islands”.

Today, coral reef ecosystems in the Marshall Islands are in excellent condition (Figure 12.2). The outer and less populated atolls in particular support healthy and diverse communities of marine life. Many threats, such as overfishing, pollution and coral disease that are common in Southeast Asia and other Pacific Islands have been comparatively low in the RMI. However, in recent years, the coral reefs in the Marshall Islands have become increasingly threatened by pressures of fisheries, climate change and sea-level rise, increased urbanization and a loss of cultural traditions. For example, the outer atolls in RMI suffer from occasional forays of fishers involved in the live fish trade and illegal shark finners. Coral reefs near the population centers at Majuro atoll (30,000) and Ebeye (15,000) are far more impacted by fishing and pollution than other parts of the RMI.

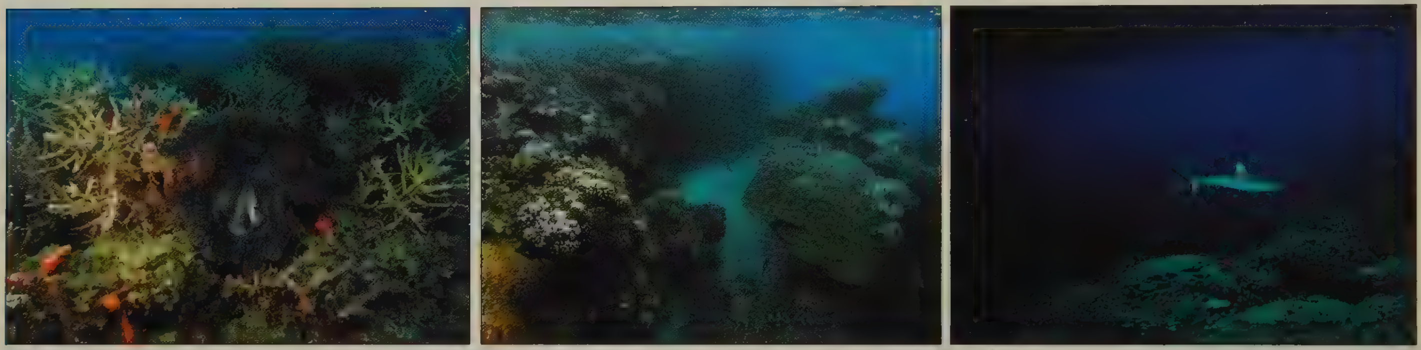


*Figure 12.2. Clear water and protected lagoons combine to ensure prolific coral growth (left). Well-developed spur and groove channels provide semi-protected habitat along the exposed atoll reef fronts (center). Apex predators, such as sharks, are still common on some RMI reefs (right). Photos: A. Seale.*

Many of the Marshall Islands’ coral reefs remain unexplored, but capacity for coral reef assessment and monitoring is growing. Over the past few years, the College of the Marshall Islands (CMI), Natural Resource Assessment Surveys (NRAS), Coastal Management Advisory Council (CMAC), Marshall Islands Conservation Society and the Re-Imman Project Team have collected baseline information on the condition of RMI coral reefs with strong support from the Marshall Islands Marine Resources Authority (MIMRA), local communities and local governments. The CMI Marine Science program is helping to build local capacity for conservation. A national database of survey data for six atolls is maintained at the CMI and MIMRA offices. The information presented in this chapter is based on these surveys, personal observations by CMI staff and reports of a University of Hawaii expedition to Ailinginae atoll in 2002. A long-term comprehensive monitoring project is underway at Rongelap and similar efforts are under development for Majuro, Ailuk and other atolls in the future.

Conservation and sustainable resource management has always been a part of Marshallese traditional culture. The increasing threats to marine resources have strengthened commitment within the RMI government and communities to establish and manage community-based conservation areas in addition to other resource conservation strategies. Over the last decade, various efforts have been made to establish community-based conservation areas on different atolls. Those conservation initiatives have been led either by MIMRA, as part of the development of sustainable local fisheries, by the national Environment Protection Authority (RMIEPA) or by local atoll governments (e.g., Mili’s 2003 efforts have stalled, but a recent initiative on Ailuk established management areas and a management plan for the atoll). Other communities and leaders are seeking protection through international conservation efforts, such as the nomination of Ailinginae and Bikini Atolls for inclusion on the United Nations Educational, Scientific and Cultural Organization (UNESCO) World Heritage Site list. In 2006, the president of the Marshall Islands signed the Micronesia Challenge, a commitment by Micronesian countries and territories to “effectively conserve” 30% of nearshore marine and 20% of terrestrial resources by 2020. The need for an overarching framework for conservation area planning was recently addressed by development of a national document outlining the principles, process and guidelines for the design, establishment and management of conservation areas that are fully owned and endorsed by local communities based on their needs, values and cultural heritage (Re-Imman Project Team, 2008).

## ENVIRONMENTAL AND ANTHROPOGENIC STRESSORS

### Climate Change and Coral Bleaching

Because the country is comprised of numerous low-lying islands that depend on intact coral reef ecosystems for protection from erosion, the RMI is particularly threatened by climate change and associated sea level rise. Among the anticipated effects of climate change are an increasing incidence of storms, drought and sea level rise. Recently Majuro Atoll suffered both a serious storm (October 2006) and an extended drought, which led to the declaration of a water emergency.

*Sea level rise*

The Intergovernmental Panel on Climate Change's (IPCC) 3rd Assessment Report (IPCC, 2001) reported that sea level has been rising an average of 0.01 to 0.02 m per century since 1000 BC, but the 4th Assessment (IPCC, 2007) established that sea level rise over 20th century was 0.17 m. For various emissions scenarios and with a nominal allowance for ice sheet effects, the IPCC projects sea level rise in the 21st century to be between 0.18 and 0.79 m, but the report also cautions that "larger values cannot be excluded" since the "understanding of these effects is too limited to assess their likelihood or provide a best estimate or an upper bound for sea-level rise" (IPCC, 2007). Rahmstorf (2007) analyzed the tendency of observed sea level rise to exceed the upper limit of IPCC forecasts, and projected a total 21st century sea level rise of 0.5 to 1.4 m unless mitigation measures are implemented.

The land area of the Marshall Islands averages about 2 m above sea level (www.rmiembassyus.org/Environment.htm); the highest elevations are generally found along shorelines with lower elevations inland (ELP, unpub. data). RMI government is very concerned with sea level rise. The potential impact of sea level rise has been demonstrated quite dramatically during extreme high tides when the groundwater lens rises above the surface in the low-lying areas. Building dykes and pumping would be impractical to maintain land below sea level, as the soil substrate is porous coral rubble. Construction of seawalls is equally unfeasible as it would require islanders to mine nearshore areas for building materials, similar to the blast mining that occurs on Majuro reef flats (Barnett and Adger, 2001) and the widespread hand mining of beaches (McKenzie et al., 2006). There is currently a move to dredge sand and gravel from lagoons (Smith and Collen, 2004) in order to conserve ocean reefs. Ocean reefs are an initial line of defence against the sea as they dissipate wave energy, provide habitat for foraminiferans which make up most of the sand in the lagoon and cement together reef structure.

Holthus et al. (1992) estimated a 7% loss to the Marshall Islands gross national product with a 1 m sea level rise through application of the Bruun (1962) rule for beach erosion. But Forbes and Solomon (1997) assert that the Bruun rule is "clearly inappropriate where shorelines have responded to past high water levels by progradation rather than recession, and where the nearshore profile is constrained by the reef flat." A regional high stand of sea level at about 2-3 m above the present level in 2000 B.C. (before human habitation) was responsible for the formation of island foundations (Dickinson, 2006). The current population center at Majuro Atoll, however, is not situated on this relatively high land at Laura, but on much lower and partially reclaimed land.

*Bleaching*

Corals in the Marshall Islands have been spared from mass bleaching events like those that have impacted Palau and the Caribbean, but observations made primarily on Majuro indicate that modest bleaching events have occurred on at least five occasions. Bleaching events in the RMI, which usually are restricted to intertidal depths, were first observed in an undated photographed used for tourism promotion between 1998 and 2000. An event beginning in September 2001 during a period of calm, cloudless weather (Abraham et al., 2005; Pinca et al., 2005) resulted in considerable coral mortality, which intensified and spread to slightly greater depths during low tides in October and November 2001. Mortality among shallow *Acropora* colonies on both lagoon and ocean shores was well documented (Jacobson, unpub. data). Local knowledge suggests that similar events did not occur in the RMI previously.

Coral bleaching at deeper sites was observed on Majuro in both 2003 and 2006. The 2003 event involved *Acropora*, *Porites*, *Millepora* and other colonies down to depths of at least 10 m. In 2006, up to 5% of massive *Porites* spp. colonies within the northern lagoon were entirely or partially bleached, but with no apparent mortality (Figure 12.3). At several lagoon sites, up to 90% of *Acropora* colonies also bleached, leading to significant mortality (approximately 20-50%) down to 3 m depth. Significantly, many massive *Faviid* and *Platygyra* colonies growing at 5-8 m on the fore reef bleached and suffered "crown" mortality in 2006. This pattern of mortality primarily affects the top surfaces of colonies and can result in scars that persist for many years; such scars had not been observed previously on Majuro (Jacobson, unpub. data). Recent subtidal bleaching events have been largely restricted to a few species and usually result in a low overall incidence of bleaching (typically less than 20% of all coral below several meters depth). The 2003 and 2006 events occurred during a period of elevated sea water temperatures,

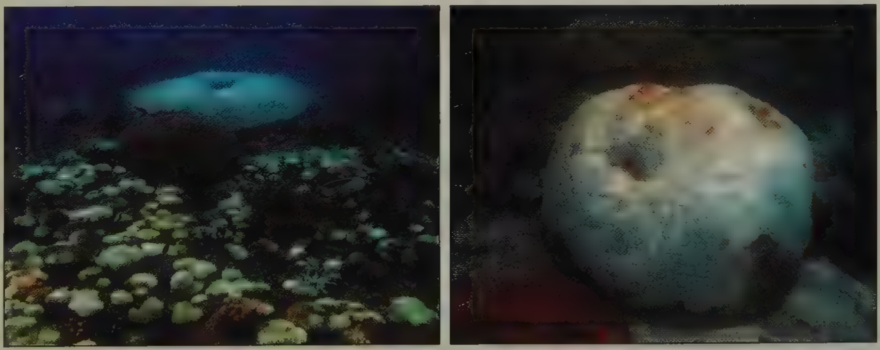


*Figure 12.3. In 2006, coral bleaching was documented in Majuro lagoon at the southern reef near the airport (left) and in the northern lagoon (right). Porites colonies appear to have recovered since then. Photos: D. Jacobson.*

which may have contributed to a subsequent coral disease outbreak. Widespread bleaching was observed on corals in the lagoon of neighboring Arno atoll in December 2006 (Richardson, unpub. data). The atoll's population of *Isopora cuneata*, an important reef-building species, was severely reduced or impacted. Only shaded colony bases survived.

Few reports of coral bleaching have emerged from outer atolls, but this is more likely due to a lack of monitoring and not a lack of bleaching. A visit to Jaluit atoll in 2003 and 2004 permitted scientists to document a dramatic subtidal bleaching event and subsequent coral mortality there. Bleaching on Jaluit during this event was restricted to tabulate colonies of *A. robusta*, a form uncommon on Majuro (Jacobson, unpub. data).

## Diseases

Coral disease in the Marshall Islands is not yet well characterized. An outbreak of *Acropora* white disease affecting tabulate colonies on the exposed outer reefs in Majuro is the most intensively documented case so far (Jacobson, unpub. data; Figure 12.4). A bacterial pathogen, *Vibrio coralliilyticus,* which has been shown to be the cause of white plague type II in the Caribbean, was isolated from Majuro lagoon in 2004 (Sussman, pers. comm.); the bacteria is known to co-occur with a large histophagous ciliate and results in brown band disease in corals of Australia's Great Barrier Reef (GBR; GBR; Willis, pers. comm). The outbreak of *Acropora* white disease has persisted for at least seven years, with a peak during 2003-2004. The peak of the outbreak coincided with the highest temperatures recorded at a lagoon site over a ten year period, and coral bleaching occurred on site at the end of 2003, indicating a possible link between temperature and disease virulence.

In 2006, disease incidence remained relatively low (annual mortality was 5% of live tabulate *Acropora* area) as it had in 2005, compared to a peak of 16% mortality in 2004. The sustained monitoring of this outbreak has revealed an interesting change in disease symptoms. In 2006 and 2007, table corals were found with large disease-killed lesions, yet little or no signs of disease spreading is visible (i.e., if any white band is present, it is restricted to a small portion of the edge of the lesion). Clearly, corals are not dying as rapidly as they had in 2004. However, following a return of warm conditions in 2006, disease incidence in 2007 appears to be increasing once again.

Two other rarely seen disease syndromes affect *Platygyra* and *Goniastrea* spp., which display progressive overgrowth with green filamentous algae (spreading at a rate of mm per week), and *Turbinaria*, in which multiple lesions expand at a rate of 2-4 cm per year (Figure 12.5). These cases of disease were found only on the southern, pollution-impacted shore of Majuro. Coralline lethal orange disease is also common on Majuro along the southern shore, and typically spreads at a rate of 1-2 mm/day (Jacobson, in prep.)

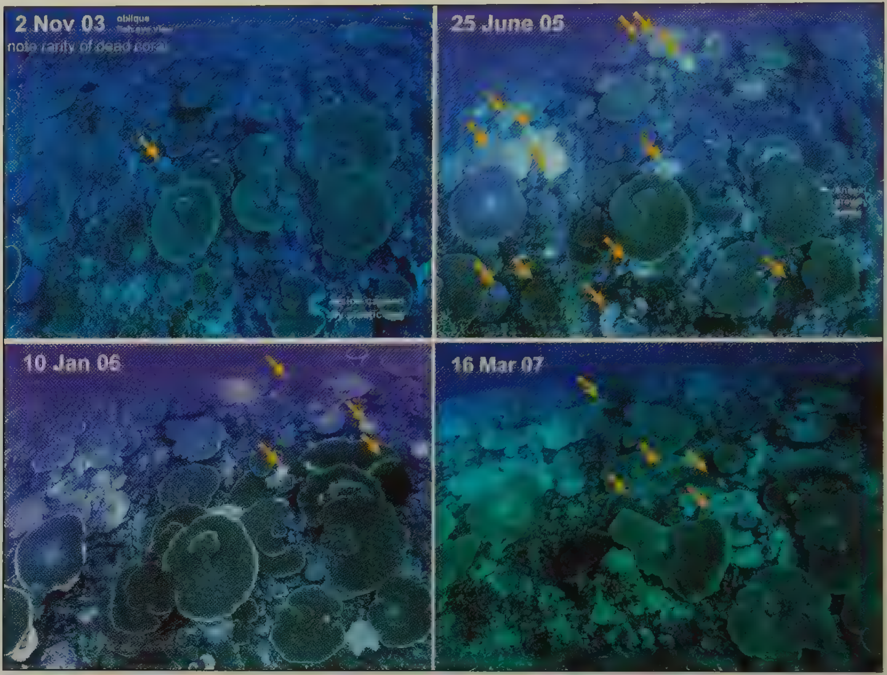


*Figure 12.4. Time series of Majuro oceanside dropoff, showing diseased and dead tabulate* Acropora *spp. Source: D. Jacobson.*

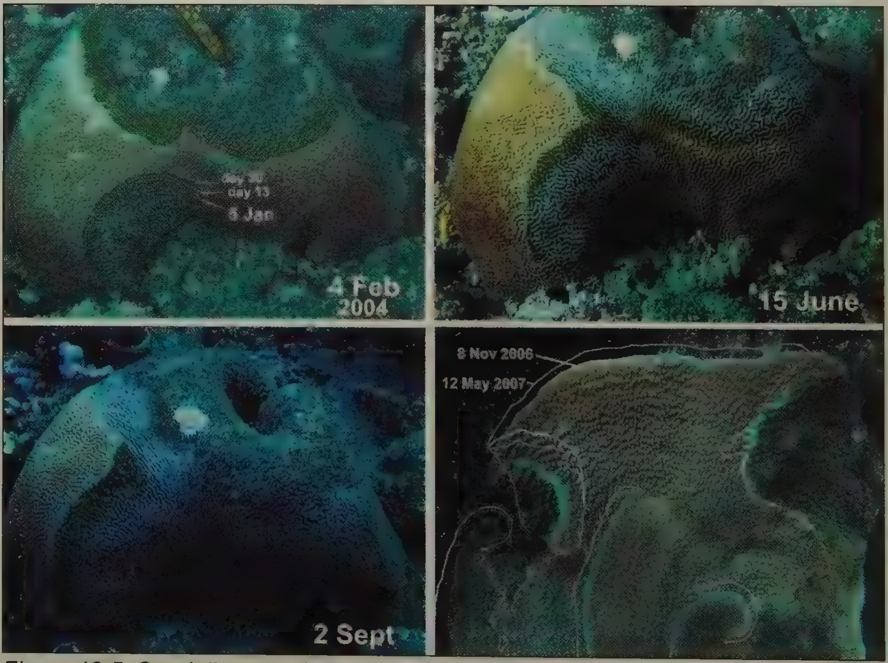


*Figure 12.5. Coral disease of unknown etiology affecting* Platygyra *(time series) and* Turbinaria. *Outlines show enlargement of lesions and coral growth after six months. Source: D. Jacobson.*

## Tropical Storms

The Marshall Islands are continuously buffeted by the Pacific Ocean. Narrow strips of land, most of which is less than a meter above high tide, are subject to erosion during storms from surge and large waves. Climate change related storms and associated surge waves threaten coral reef communities (Madin and Connolly, 2006), terrestrial natural resources and the livelihood of thousands of people in the Marshall Islands. Past typhoons and tidal waves have devastated parts of Majuro, Arno, Mili, Jaluit, Likiep and Namdrik atolls, and such storm phenomena are expected to continue and possibly intensify with global warming.

An October 7, 2006 storm (which later became Typhoon Soulik) caused large surf and a storm surge that flooded areas of Majuro, inundating parts of the highway and destroying a section of the airport seawall (Figure 12.6). Large tabulate *Acropora* colonies were damaged, coral rubble and trash were deposited on the island and some breadfruit trees were killed when salt water pooled around their roots (Figure 12.7). Fortunately, beach erosion was partially or completely offset by the transport and accumulation of coral rubble. However, the long-term effects of coastal erosion are readily apparent on Majuro, where waves have undercut the shoreline, causing the collapse of coastal land and coconut palms. Recovery of coral reef communities from single and chronic catastrophic events, such as, storms is expected to be slow in situations where the physical environment has been altered (Connell, 1997).

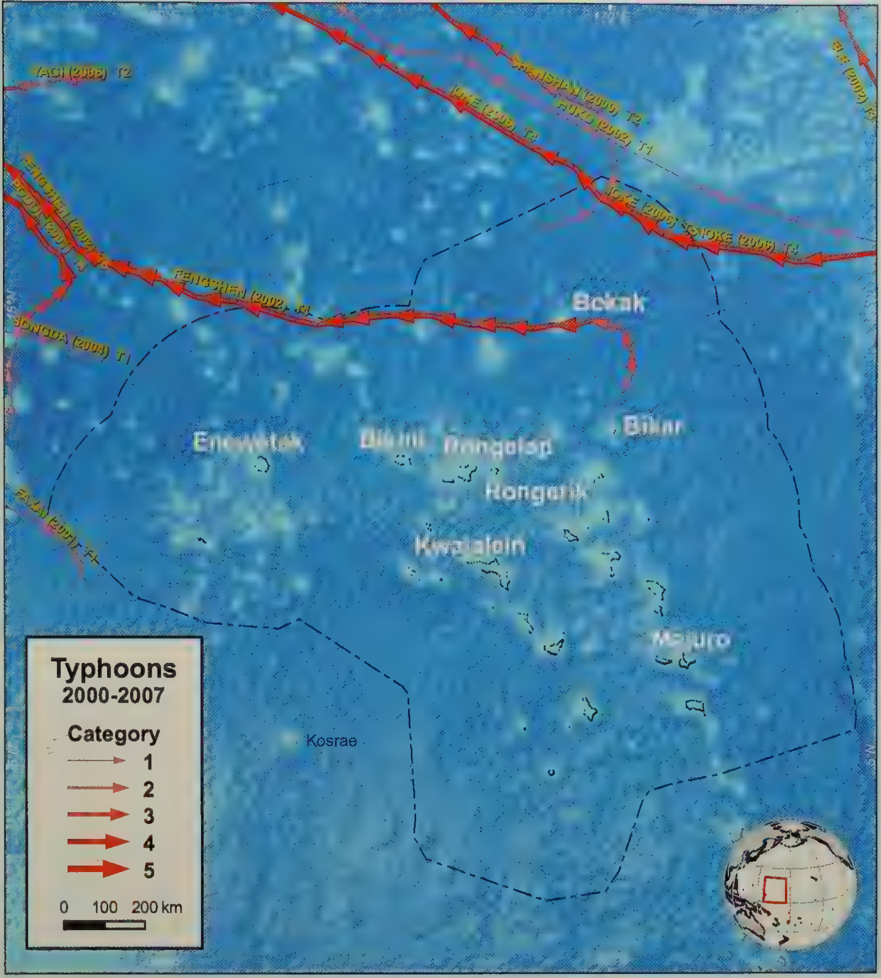


*Figure 12.6. The path, name, year and intensity of typhoons passing near the RMI from 2000-2007. Many Pacific typhoons are not named or the names are not recorded in the typhoon database.* **NOTE:** *Because Typhoon Soulik was a tropical storm when it passed the RMI, it does not appear on this map. Map: K. Buja. Source: http://weather.unisys.com/hurricane/.*

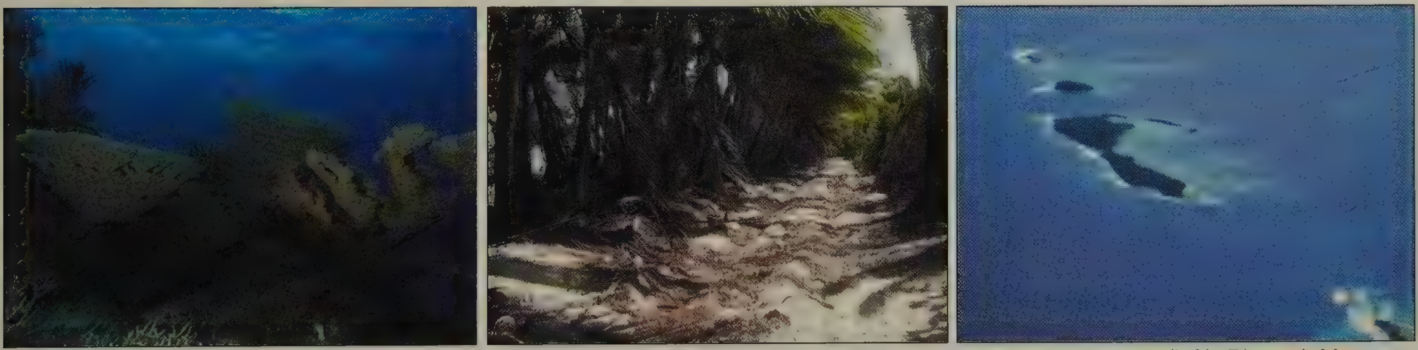


*Figure 12.7. Plating Acropora species common in lagoon habitats are particularly vulnerable to storm damage (left). Photo J. Maragos. Narrow low sand dunes separate the lagoon and ocean at Arno Atoll and provide little defense against storm surges (center). Photo: Z. Richards. Narrow strips of land on Kwajelein atoll rim (right). Photo M. Beger.*

## Coastal Development and Runoff

The requirements for sand, large rock and aggregate for local construction have traditionally been met by shore-based lagoon dragline dredging and reef flat blast quarrying (Figure 12.8). Although the long-term recovery of coral reef communities from this practice are not well studied, shallow reef flat quarry pits near the airport on Majuro and on Enewetak Island that were dredged in the past have developed extensive coral growth and high fish diversity over the intervening decades. However, recent quarrying in an area west of the Majuro airport produced deep (about 7 m) pits filled with a fine sediment that reduces the potential for coral recruitment at these sites. At one site where quarrying intersects the coral rich edge of the lagoon reef flat, the adjacent shallow reef is in surprisingly good condition and continues to support high coral cover. Over the long term, however, removal of the lagoonal reef flat may increase the vulnerability of adjacent shorelines to storm erosion and increase the amount of sediment discharged onto nearby reef habitats.

The threat of increased coastal erosion and the loss of some lagoon beaches have prompted a move to outlaw shore dragline dredging on Majuro. Of the two alternatives, suction dredging and importing aggregate, the latter is more expensive. As a result, plans are being made to suction dredge materials from deeper (below 10 m) areas of the northern lagoon where accumulation "deltas" of foraminifera sand are found (see the Associated Biological Communities section of this chapter for a summary of the area's foraminifera ecology). However, land owners in the northern lagoon oppose this choice, so it is likely that suction dredging will be restricted to areas of the southern lagoon, despite the disadvantage of smaller grain size. Finding environmentally friendly local sources of aggregate and hard rock is more problematic.

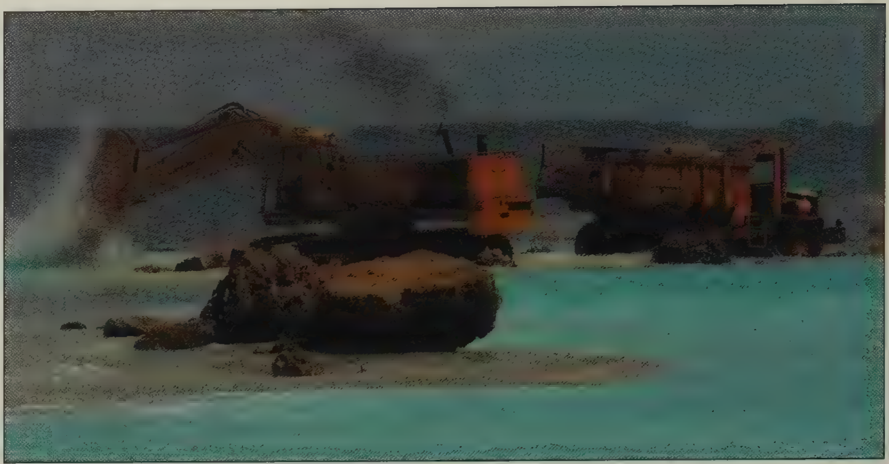


*Figure 12.8. Mining of hard rock along edge of lagoon fringing reef near Majuro airport, 2007. Photo: D. Jacobson.*

## Coastal Pollution

Due to the collapse of the solid waste collection system between 2004 and 2007 (e.g., corroded dumpsters and broken down trucks) and insufficient toilet facilities, much household waste, as well as most fecal waste, was simply deposited along Majuro's shoreline. The lack of an effective seawall barrier at the landfill allowed large amounts of floating garbage to escape, blanketing down-current shores with myriad bits of plastic refuse, especially bags and diapers, which can be found in the water column, particularly during high wave events. Much of this garbage becomes entangled on coral.

The solid waste landfill on Majuro is nearing capacity. A local non-governmental organization (NGO), the Marshall Islands Conservation Society, with New Zealand and U.S. funding, has implemented a new recycling program to increase composting of plant waste (with cardboard soon to be included) and begin community battery collections in an attempt to extend the life of the landfill and divert toxics from the environment. Regardless of improvements in waste management, black leachate continues to escape from the landfill onto the adjacent reef flat with potentially serious ramifications for the reef ecosystem. For this reason it is crucial to prevent the development of new landfills elsewhere on the atoll. In early 2007, the responsibility for solid waste collection was placed under a single authority, the Majuro Atoll Waste Corporation. Despite a perennial shortfall of funding, the corporation has succeeded in fortifying the seawall and stabilizing the refuse with a cover of sand dredged from the lagoon. Although incineration has been proposed as an alternative waste management strategy, the high cost of the incinerator and concerns over hazardous by-products (e.g., toxic emissions and ash) has prevented adoption of this option. Though the use of plastic bags and Styrofoam packaging for food is clearly unsustainable, these practices persist in urbanized areas and are expanding to outer atolls. In a small step in the right direction, the CMI has committed itself to use only biodegradable packaging, and encourages its vendors to do the same.

## Tourism and Recreation

The good of RMI's coral reefs and islands, and the historical significance of the RMI appeals to SCUBA divers, sport fishers and World War II history enthusiasts. The country currently hosts approximately 6,000 visitors per year, of which 20% (roughly 1,200) are tourists, primarily from the U.S. and Japan (Figure 12.9). On Majuro, the areas of the northern lagoon are in excellent condition and remain the focus of reef-related tourism. Most of these developments consist of small-scale resorts on northern islets and a few dive shops. In 2007, the first in a series of Japanese charter flights brought in a large group of SCUBA tourists to Majuro.

Other than the small number of yachts visiting RMI's outer atolls each year, few tourist operations exist on outer atolls, largely because of unreliable air transport. On Bikini

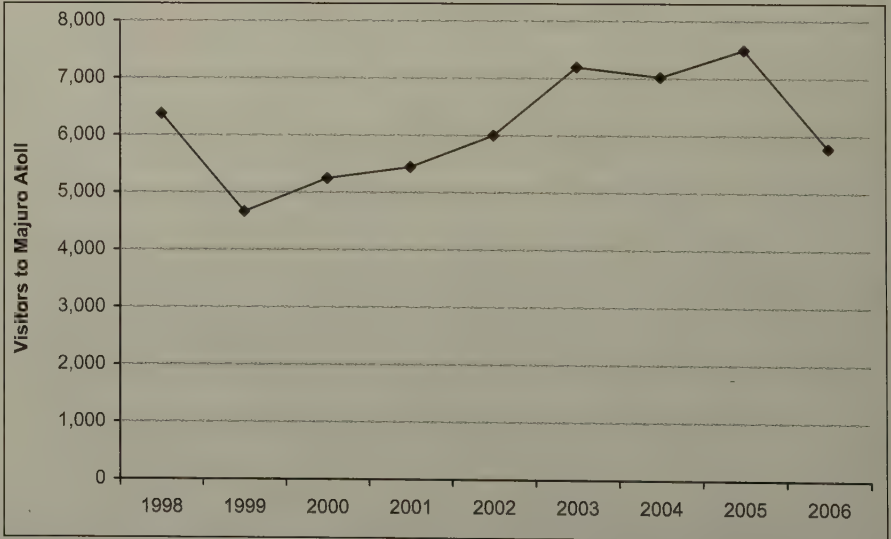


*Figure 12.9. Visitors arriving at Majuro Atoll by air. Source: Marshall Islands Visitors Authority.*

Atoll, a community-based SCUBA diving center attracts tourists eager to explore a historic collection of WWII wrecks and visit Shark Pass, a part of the atoll that has received international attention thanks to a spectacular population of grey reef sharks. Unfortunately, the shark population at Bikini was significantly depleted by a recent visit from a single illegal shark fishing operation, highlighting the vulnerability of these outer islands to illegal fishing. A new resort is under development on Rongelap that will allow tourists to visit the atoll, which has been virtually inaccessible since the nuclear tests conducted in the 1950s. Plans have also been announced for the development of a large-scale Korean golf resort and paved airport on Wotje Atoll, which will require the relocation of the population center to adjacent islets. A lack of other local economic opportunities makes the plan attractive to locals, and this reality tends to override concerns about the potentially harmful affects of excess water and nutrients on the marine and terrestrial environment. While outer atoll destinations offer unparalleled diving and fishing opportunities, the remoteness of these atolls is a barrier to tourism development as well as environmental surveillance capacity.

## Fishing

Copra has historically been the RMI's sole cash crop. Over the past ten years, however, increased production from Southeast Asian countries has negatively impacted the price of copra and, as a result, RMI has focused more heavily on its fisheries for income. The RMI's Exclusive Economic Zone of over 2,128,970 km$^2$ (822,000 mi$^2$) supports a large population of high-grade tuna, including skipjack, yellowfin, bigeye and albacore. The RMI fisheries operate in accordance with the Forum Fisheries Agency, the regional fisheries regulatory body. The RMI, through the Ministry of Resources and Development, is pursuing a number of development opportunities in fisheries and maintains bilateral fishing agreements with several countries, including Japan, Korea and Taiwan. The licensing fees charged to foreign fishing vessels generate the majority of revenue from this resource.

A China-based fish processing plant is currently under construction on Majuro and is scheduled to begin operations in early 2008. The new plant will supply cooked loins for the canned tuna industry. Due to the wide variety of retail operations, dry dock and harbor facilities, the availability of international air service and access to fuel supplies, Majuro is a competitive location for fishery growth in the region.

Sharks, a valuable tourism resource, have declined in many parts of the Pacific. While some believe that the RMI still supports robust reef shark populations, there is evidence that shark populations are starting to decline (Figure 12.10). Shark fins continue to be exported from Majuro, allegedly as bycatch from the long line tuna fishery. There seems to be little concern for the fate of shark populations among the Marshallese, who fear sharks for their perceived danger.

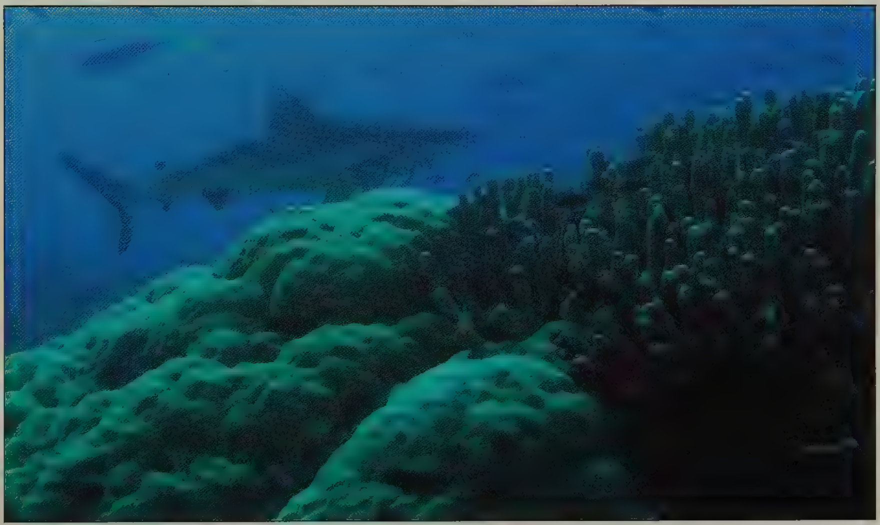


*Figure 12.10. A healthy population of grey reef sharks on Ebon atoll still exists (as of 2005) but populations have been seriously depleted on some other atolls. Photo: D. Jacobson.*

## Trade in Coral and Live Reef Species

Captive breeding or aquaculture ventures in RMI are a boom and bust business. The most successful operations include MIMRA-operated tridacnid clam hatcheries on Majuro, Likiep, Mili and Arno Atolls. Coral fragments are also produced sustainably for the ornamental aquarium trade and are marketed to North America and Europe. Collection of live aquarium fish takes place primarily in Majuro, but also on Arno and Mili, and continues to be unregulated and unmonitored. Many high value target species (e.g., some butterflyfish and angelfish) are found only in deep (>50 m) habitats; their natural history is largely unknown and therefore the sustainability of these fisheries cannot be assessed. In 2006, over 52,000 individual fish were exported from Majuro (D. Jacobson, pers. obs). Various attempts have been made to farm rabbitfish (*Siganus* spp.), sea cucumbers and seaweed on various atolls in the country. CMI has promoted aquaculture via the Arrak research station, a research facility that includes classrooms, an algal culture laboratory, a basic science laboratory, an indoor hatchery, larval rearing tanks and grow-out facilities. In 2007 an Australian company began operating a fish farming operation that imports juveniles of barramundi cod (*Cromileptes altivelis*) for grow-out in the Majuro lagoon. The Black Pearls of Micronesia project is one of the first commercial pearl farms on Majuro.

## Ships, Boats and Groundings

Shortly before Christmas 2006, a 23 m abandoned Indonesian style wooden boat drifted onto the southern Majuro shore, where it became entrapped on the reef flat (Figure 12.11) and shifted back and forth along the shore for six days. After it cleared the reef, it continued drifting westward, smashing a narrow band of coral and dislodging large chunks of substrate along 10 km of shore. Efforts to remove the vessel failed.

In the spring of 2007, the near sinking of a dive boat at its mooring led to it being towed across the lagoon and intentionally beached in shallow water in an attempt to salvage the vessel. This resulted in a diesel spill, the destruction of several dozen *Porites* colonies and the near-destruction of an endemic three banded anemone fish colony (Figure 12.12). This site is a popular, formerly intact snorkeling area in the northern lagoon of Majuro. Litigation resulting from this incident is ongoing and has the potential to result in a landmark, precedent-setting ruling for local environmental law enforcement.

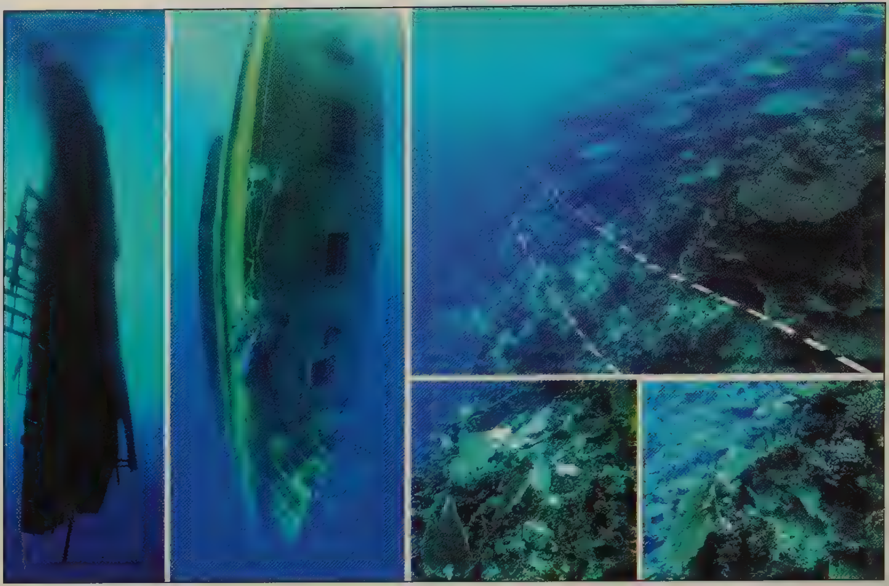


*Figure 12.11. In 2006 an abandoned, partially sunk wooden boat (resembling an Indonesian fishing vessel) resulted in several days of reef damage along the dropoff, as the currents moved the wreck back and forth along the central southern shore of Majuro atoll. Photos: D. Jacobson.*

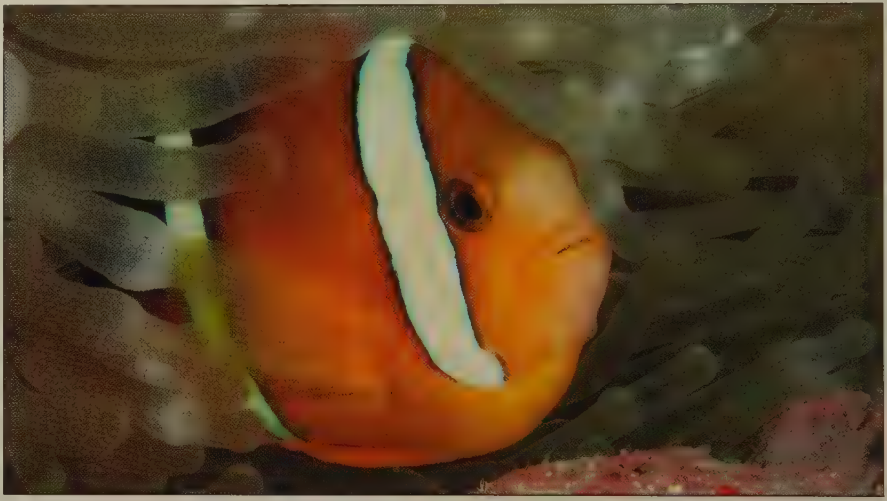


*Figure 12.12. A colony of three-banded anemone fish, which are endemic to RMI, were impacted by the attempted salvage of a grounded vessel. Photo: J. Maragos.*

## Marine Debris

Due to their location within the northern equatorial current, Marshall Island atolls receive large amounts of marine debris, primarily composed of glass, plastic, rubber and other products which accumulate on the shorelines of all atolls (Figure 12.13). Based on the identity of bottles and identification of floating seeds, it appears that some of the debris originates from as far as Central and South America (Vander Velde and Vander Velde, 2006).

In addition to receiving marine debris from distant locations, Majuro exports a large amount of plastic trash to the Pacific current system. An extraordinary amount of rubbish can be found in the reef habitats of Majuro, on both ocean and lagoon shores (Figure 12.13). Disposable diapers are among the most abundant and destructive debris because they stick to corals and do not degrade for lengthy periods of time. Continual abrasion kills the local coral polyps. Plastic bags and other plastic products can reach surprisingly high densities in the water column.

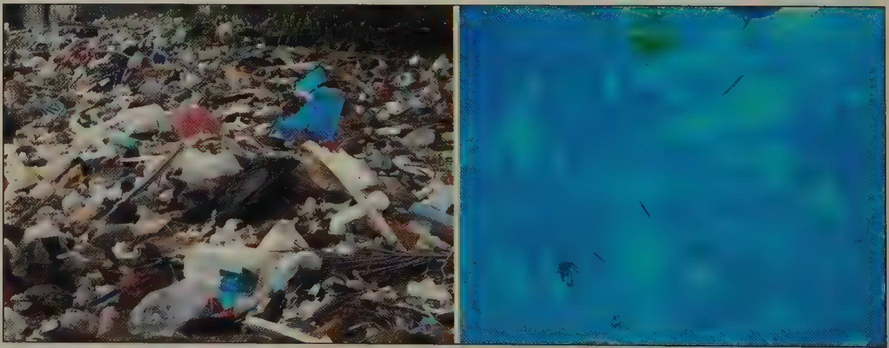


*Figure 12.13. Plastic debris from both distant and local sources accumulates on Majuro shores, both lagoon and oceanside (left). Underwater view near the solid waste landfill before construction of a seawall (right). Photos: D. Jacobson.*

## Aquatic Invasive Species

Although macroalgae of the genus *Kappaphycus* was briefly introduced and successfully cultivated in Majuro lagoon in 2002 as a pilot aquaculture project, this potentially invasive brown algae has evidently not become naturalized. Some years ago *Acanthophora spicifera*, another macroalgae species, became abundant in Majuro lagoon. The potential exists for the non-native humpback grouper (*Cromileptes altivelis*) which was recently imported for aquaculture in lagoon cages, to become naturalized. The giant clam species *Tridacna derasa* was introduced as an aquaculture species, and anecdotal evidence suggests that individuals still survive at Mili and Arno atolls.

## Security Training Activities

The military base at Kwajalein Atoll was established in 1964 and supports the research and development needs of U.S. space and defense programs. The facility provides strategic missile defense program support as the Ronald Regan Ballistic Missile Defense Test Site (RTS), where the military conducts research, development, testing and evaluation using cutting-edge radar, optical and telemetry sensors. The $4 billion strategic military base and the large lagoon at Kwajalein Atoll provide an ideal location for testing long-range missiles launched from the continental U.S. and short to intermediate range missiles launched from elsewhere in the Pacific. In addition to military operations, RTS supports NASA and Department of Energy initiatives.

## Offshore Oil and Gas Exploration

There are currently no offshore oil and gas exploration activities occurring in the RMI.

## Other

### *Crown-of-thorns Sea Star (COTS)*

No published record of elevated COTS (*Acanthaster plancii*) population numbers in the RMI occurred in the three decades following an event in the early 1970s, when a large outbreak triggered a professional control effort across Micronesia led by Westinghouse personnel from San Diego (D. Jacobson, unpub. data). However, in 2004 several concentrated aggregations (over 1,000 animals/km$^2$) were found in Majuro's southwestern lagoon and northern pass. Although this outbreak has subsided in most monitored regions without significant human intervention, dense aggregations persisted in some areas in 2007, including one to the west of the northern pass. Most of the lagoon is not currently monitored for COTS, so data on their abundance and distribution is collected opportunistically.

A pilot control project conducted in Majuro during the initial stages of the 2004 outbreak removed over 900 animals from a 1 km long segment of fringing reef in the southwestern lagoon. Despite these efforts, the region suffered heavy coral mortality when other COTS replaced the removed individuals. The result of this lagoon outbreak was over 90% mortality among *Acropora*, heavy mortality among massive colonies such as *Pavona* spp. and *Lobophyllia* spp., and locally high mortality (50-75% mortality, mostly in the west) among massive *Porites* colonies (D. Jacobson, unpub. data; Figure 12.14). The loss of large *Porites* colonies, which are estimated to be more than 100 years old, is significant, especially considering that COTS generally avoid consuming *Porites* spp. elsewhere (D. Jacobson, unpub. data). In the northern reaches of the lagoon, a patchwork of devastated reefs are interspersed with areas of low mortality. *Pavona cactus*, *Acropora*, *Goniastrea* and many other species have been heavily impacted, with more than 95% overall coral mortality on some formerly pristine, highly diverse reefs (D. Jacobson, unpub. data).

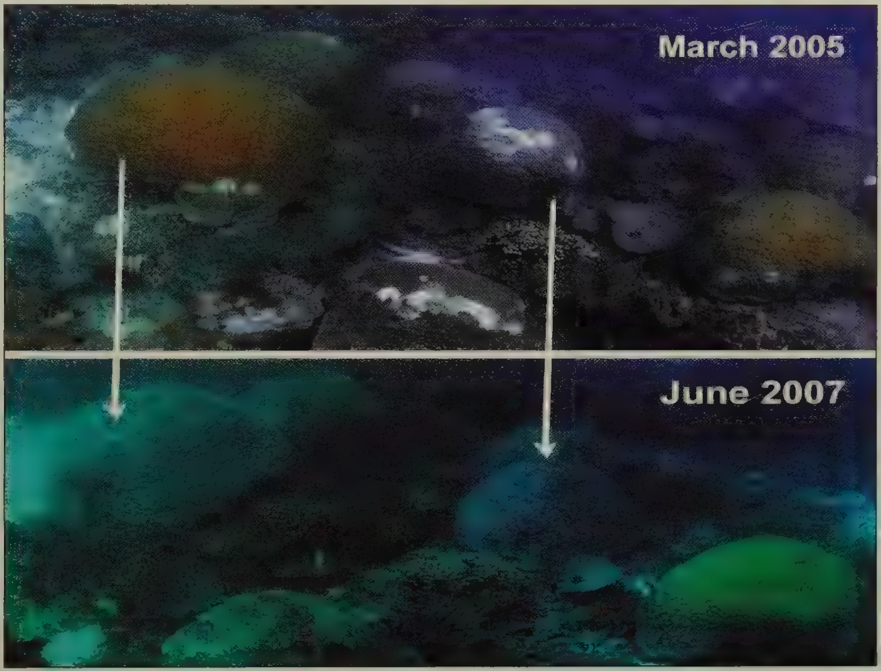


*Figure 12.14. Majuro lagoon time series showing demise of large (2-3 m)* Porites *colonies from COTS predation. Photos: D. Jacobson.*

On the ocean shore, predation by COTS caused high mortality among large table corals off Majuro's west coast (near the town of Laura) in areas where disease mortality was also high. The outbreak seems to have spread to the east where COTS have continued to attack massive *Porites* colonies while avoiding branching or columnar species of *Porites* (i.e., *P. rus* and *P. cylindrica*). A number of smaller COTS (< 25 cm) have recently been observed near the airport.

During a brief visit to Ebon atoll in 2005, lagoon reefs exhibited significant damage associated with a COTS outbreak that persisted throughout the 1980s and 1990s. Ebon's ocean reefs appear to have largely escaped mortality. Because most of the lagoon's coral colonies had been devoured previously, by 2005 Ebon lagoon's COTS population was comprised of only about a dozen animals that were observed on a large patch reef (D. Jacobson, unpub. data).

A very small population of eight COTS was also found on a small patch reef in Ailuk lagoon in June 2006. COTS are routinely found in low abundance on islands such as Majuro and Likiep. Efforts to collect additional information on COTS populations at other atolls will be facilitated by the installation of an environmental radio network, which will improve communication between atolls.

## CORAL REEF ECOSYSTEMS—DATA-GATHERING ACTIVITIES AND RESOURCE CONDITION

Although there are few consistent monitoring activities ongoing throughout the Marshall Islands, a number of programs have performed assessments at targeted locations in the RMI. Much of the repetitive work is conducted at Majuro Atoll, where a large proportion of the population resides. A number of assessments have been performed at the remote atolls as well. These activities are summarized in Table 12.1. NRAS monitoring locations are pictured in Figure 12.15.

*Table 12.1. Data-gathering activities conducted in RMI since 2000. BDS – biodiversity swims, REA – Rapid Ecological Assessment based on transects, TS – terrestrial and turtle surveys, CS – community surveys, CB – capacity building, S – single assessment in multiple sites, Moni – temporal monitoring program.*

| ATOLL | OBJECTIVES | START DATE | FUNDING | PARTNERS |
|---|---|---|---|---|
| **ASSESSMENTS** | | | | |
| Likiep | Assess reef-fish | 2001 | MIMRA | CMI |
| Ailinginae | BDS, REA, CB, TS (all S) | June 2002 | NFWF | CMI, UH, UQ |
| Bikini, Ailinginae and Rongelap | BDS, REA, CB, (all S) | July-Aug. 2002 | USDOI, Small Rufford Grant | NRAS |
| Mili, Rongelap | BDS, REA, CB, (all S) | July-Aug. 2003 | USDOI, NFWF, MIMRA, Point Defiance Zoo and Aquarium, CMI and RalGOV | NRAS |
| Namu, Majuro | REA, CB, (all S) | Nov.-Dec. 2004 | US-DOI, UH Sea Grant, MIMRA, PADI Project AWARE Point Defiance Zoo and Aquarium, CMI | NRAS |
| Ailuk | REA, CB (all S), CS (ongoing) | May 2006;<br>Sept. 2006-Dec. 2007 | US-DOI, Winifred Scott, Point Defiance Zoo and Aquarium, MIMRA, Regional Natural Heritage Program, CMI | NRAS, University of Tasmania, Marine and Environmental Research Institute of Pohnpei, WAM |
| **LONG-TERM DATA-GATHERING EFFORTS** | | | | |
| Rongelap | BDS, REA, CB, PH-tra (all long-term Monitoring) | Dec. 2006 | BP-conservation programme, NOAA | CMI, MIMRA, University of Queensland, James Cook University, Victoria University |
| Ailuk, Likiep, Majuro, Arno | REA, CB, | Aug.-Sep. 2007 | SPC CO-Fish | SPC, MIMRA |

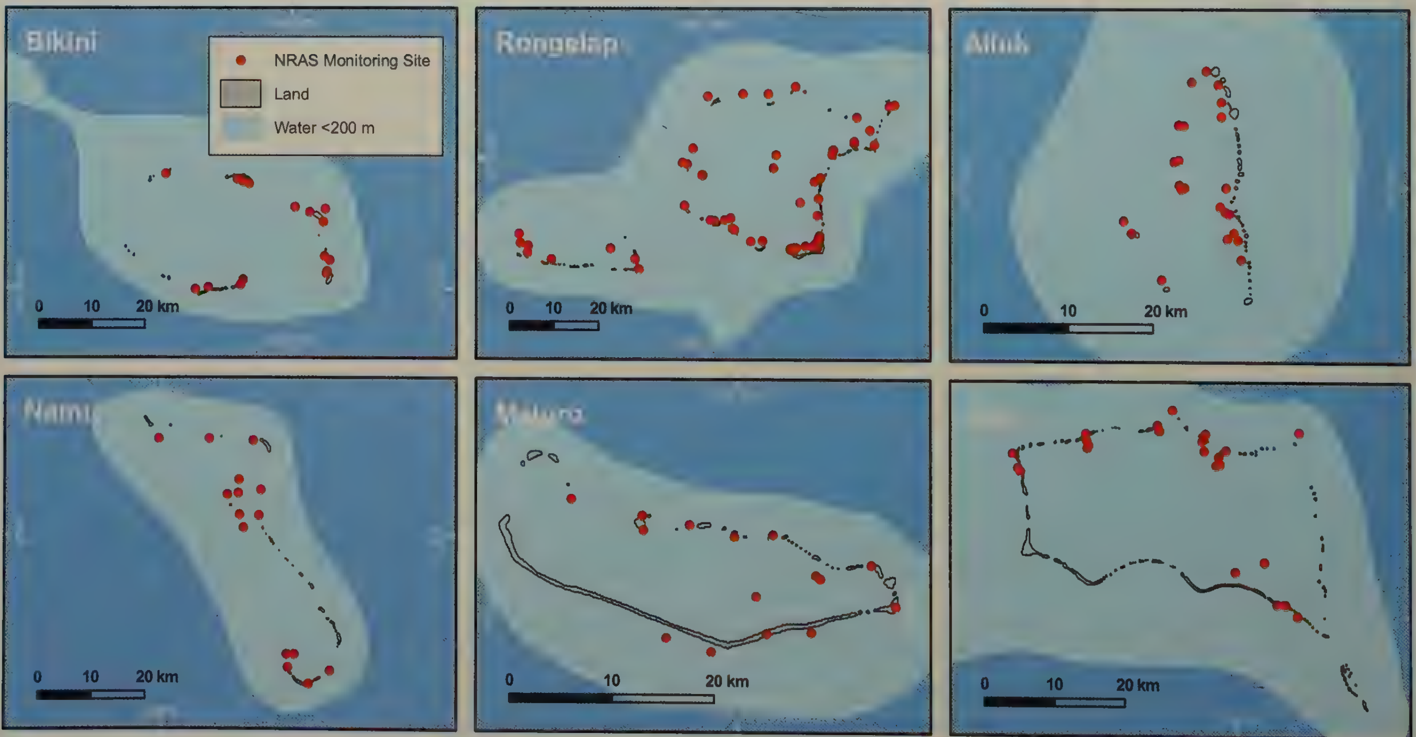


*Figure 12.15. A map of the NRAS monitoring locations in the Marshall Islands. Map: K. Buja.*

## WATER QUALITY AND OCEANOGRAPHIC CONDITIONS

Leachate from unlined landfills is a major concern for reef condition in the RMI, particularly on Majuro. Until recently, many toxic substances, including materials from batteries and electronic waste, were simply dumped on the reef flats. A new program in Majuro has helped correct this problem and now diverts most toxic materials from the landfill for recycling.

Eutrophication is also a major concern for reefs near urban centers. The most heavily impacted regions, such as areas adjacent to Majuro's sewage outfall and landfill, are characterized by the presence of a conspicuous black, non-calcified encrusting red alga that can occupy up to 30% of substrate (D. Jacobson, pers. obs.). This algae has not been detected elsewhere in the RMI, or in less-populated parts of Majuro. Impacted areas also contain an abundance of algal species that are rare are absent in the other parts of the RMI, including *Dictyota* sp., *Padina* sp. and certain cyanobacteria. In addition, coral diversity and tridacnid clam abundance is very low in these impacted areas and the disease outbreak among acroporid corals is restricted to this region.

Recent events indicate that heavy metal pollution may be exerting a negative impact on invertebrate populations. Six or seven years ago a pearl farm was forced to relocate from Majuro due to high mortality rates experienced by adult pearl oysters. Another local pearl oyster hatchery in the western lagoon, far from the population center, has been plagued by high larval mortality for several years. After the addition of the metal-chelating agent EDTA in 2006, oyster mortality was sharply reduced (D. Jacobson, pers. obs.). Such effects of heavy metals on invertebrate recruitment may be a contributing factor in the decline of Majuro's tridacnid clam populations.

The construction of a large Taiwanese dry dock in Majuro lagoon to support the Pacific "superseiner" fleet is being planned for in 2008. It is unclear how activities at this industrial site will impact nearby marine ecosystems.

## BENTHIC HABITATS

It appears that many coral reefs in the RMI have so far been spared from the destructive effects of COTS outbreaks, disease, bleaching and destructive fishing methods that are apparent in so many other locations. Outer island conditions are largely excellent and contain unique features. For example, certain reefs on Namu atoll have unusually tall, statuesque *Millepora* towers. Some areas are densely colonized by large *Stylastrea* colonies, while elsewhere on Namu, extensive strands of yellow *Turbinaria* dominate the benthos. Likiep's reefs contain a *Turbinaria* super-colony that forms an unusually large mound, and the island's fore reef walls boast nearly 100% live coral cover dominated by *Isopora* and *Montipora*. On southwestern Arno, the reef hosts unusually large and abundant *Heliopora* colonies, a colony of *Leptoria* measuring several meters in width, and exhibits very high coral diversity, including species such as *Symphyllia*, *Lobophyllia*, *Echinopora*, *Platygyra*, *Oxypora*, *Merulina*, *Oulophyllia* and *Favia*. Another reef with very high coral cover on Ebon is dominated by relatively few coral species (mainly *Isopora*, *Porites* and *Montipora*, with very few large *Acropora* colonies). At least one outer atoll still boasts a large *Tridacna gigas* population, this species has been severely reduced by illegal fishing in recent decades and is a sensitive indicator of level of exploitation.

RMI atolls are unique because they enclose deep lagoons that provide immense areas of sheltered habitat conducive to coral growth. Lagoonal locations provide a surprisingly diverse community of reef organisms. Large stands of branching *Acropora* dominate considerable portions of the lagoon floor in many RMI atolls. Within the northern RMI atolls, large "tree-like" morphotypes of *Acropora tortuosa* occur in monolithic stands; such "old growth" coral communities are thought to be rare among modern day reefs. Within the lagoon of northern atolls, including Likiep, Ailuk and Rongelap, populations of *Pectinia* and other rare corals such as *Hydnophora grandis* are found. Numerous species formally known only from southeast Asia (e.g. *Acropora kimbeensis*, *Acropora halmaherae*) were also found to have established healthy populations at Rongelap Atoll. Numerous distinctive coral and fish species are likewise restricted to lagoonal reef habitats in the RMI (Z. Richards and M. Beger, pers obs.). Inter-reef habitats and other deep benthic habitats remain relatively unexplored.

In contrast to this diversity, the most common coral in Majuro lagoon is *Porites rus*, a fast-growing species that can form extensive monospecific stands, particularly in areas that have been disturbed. Some parts of Jaluit contain stands of *P. rus*, but it is extremely rare on Ailuk where just two small colonies were found during 30 dives. Another common Majuro coral, *Acropora clathrata,* and several other tabulate species dominate much of Majuro's southern fore reef but is absent from northern atolls. Clearly, there is a wealth of biogeographic patterns within the Marshall Islands and across the Pacific Ocean that have yet to be elucidated.

The proportion of families present within Scleractinian coral communities peaks with the families Acroporidae and Favidae as predicted by Bellwood and Hughes (2001) for the GBR, however, RMI coral communities show deviations from the predicted patterns for other families (Figure 12.16). The proportion of species within the genus *Poritidae* and *Dendrophyllida* appears to be less diverse than expected, and the family Pocilloporidae appears to be more diverse than in other locations tested. Thus, the community structure and assemblages of corals in the RMI is unique and worthy of special management protection.

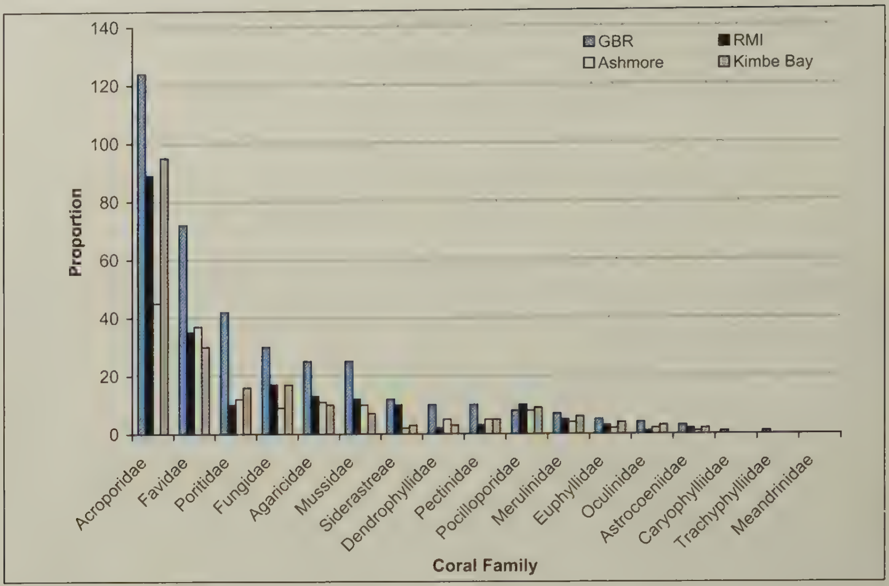


*Figure 12.16. The proportion of families present within Scleractinian coral communities. GBR data from Bellwood and Hughes (2001); Ashmore data from Kospartov et al. (2006); RMI and Kimbe Bay data from Richards (unpub.).*

## *Natural Resources Assessment Surveys (NRAS)*

Given the realities of population growth and the potential for resource exploitation throughout the RMI, it is important to collect as much baseline data on the surrounding coral reef habitats as possible. NRAS-Conservation, a local NGO, along with the CMI and MIMRA began such efforts to document the status of RMI reefs. NRAS expeditions comprising a team of 9-10 international and local Marshallese scientists surveyed reef habitats at Likiep (2001), Bikini (2002), Rongelap (2002-2003), Mili (2003), Namu (2004), Majuro (2004) and Ailuk (2006). The NRAS surveys include baseline data on fish, sharks, corals, invertebrates and marine algae. Summary information is available at: http://www.nras-conservation.org. NRAS rapid ecological assessments (REAs) are intended to serve as baseline data for managers and scientists to aid in the establishment of Marine Protected Areas.

### *Methods*

The NRAS survey methods provide data on benthic composition and coral community structure along a series of four transects located at predetermined depths (Table 12.2). Coral and substrate data are collected by a diver swimming along each 50 m tape and recording the type of substrate (e.g., bedrock, rubble, sand, dead and live coral, seaweeds and coralline algae) below the tape at 50 cm intervals (English et al., 1997; Pinca, 2005). This line-intercept method of assessment was selected to best characterize the area as a whole, taking into account the range of depth and zones present (Pinca, 2005).

Data on fish, invertebrates and macroalgae were also collected along four 50 m transects located at predetermined depths. More detailed fish and invertebrate survey methods are summarized in the Associated Biological Communities section. Data on the abundance and composition of macroalgae were collected by placing a 25 x 25 cm quadrat next to the transect line at 0, 10, 20, 30 and 40 m. Target genera and larger groups were identified, and percent coverage of each was approximated inside the quadrant and averaged for each depth. Abundance estimates were recorded according to a qualitative scale of rare, abundant and dominant.

*Table 12.2. Methodologies used for NRAS surveys. Source: http://www.nras-conservation.org.*

| ACTIVITY | TYPE OF DATA | METHOD | FINAL INFORMATION |
|---|---|---|---|
| Coral and Fish Diversity Surveys | Species list per site, semi-quantitative abundance | Timed swim | Coral and fish species lists and abundance |
| Line Intercept | Percent cover of coral and benthos; two or three replicates at each site, at different depths between 5 and 15 m | 50 x 5 m line transect, substrate type, life forms of corals, main genera and species | Percent cover composition of benthos and main scleractinia secies or genera |
| Belt Transect | Fish id, counts, size estimate; invertebrate id and counts; two or three replicates at each site, at different depths between 5 and 15 m | 50 m x 5 m x 5 m transect, fish families and commercial target species counts and class sizes; commercial invertebrate counts | Fish abundance by families and main species; invertebrate abundance |
| Algae Quadrats | Percent cover of algae and semi-quantitative abundance of major groups: four replicate per transect | Four 25 cm x 25 cm quadrats | Algae families and species id and diversity |
| Macrofauna | Timed swims | Identify and count sharks, rays, napoleon wrasse, turtles | Abundance of macrofauna |

Coral species richness was surveyed during 60 minute timed swims at each survey site. This method involves an initial direct descent to 30 m, followed by a slow, zigzag ascent to shallow parts of a reef (Beger and Pinca, 2003). Coral species were given an abundance rating according to the DAFOR scale (relative abundance scale: dominate, abundant, frequent, occasional, or rare). Overall percent cover of live coral was estimated for each site, and the three most dominant coral species were recorded (Beger and Pinca, 2003). The results of the surveys are reported in the order in which they were conducted.

### *Results and Discussion*

### Likiep Atoll Assessments (2001-2003)

A general marine survey and assessment was carried out at Likiep atoll from July 29 to August 20, 2001 (Pinca 2001). The project was undertaken to address both the needs of MIMRA as well as requests from the local government and the Marshallese people for marine surveys and stock assessments. At this time, MIMRA started to show interest in gathering data to begin a process of delegation of responsibility for coastal resources management to local government councils. This project was the first pilot project conceived to furnish such information. Several underwater surveys around six islands in the atoll, as well as interviews with the local people and fishermen were conducted by a team of seven people. An important part of the project included the training of the participants to assess marine resources. This training resulted was particularly successful and yeilded expert staff that could be deployed in similar assessments.

### Rongelap Atoll Assessment (2002, 2003)

Rongelap is a small atoll comprised of 61 islets with a total land area of just over 3 mi$^2$. Located in the northernmost part of the RMI's Ralik Chain, Rongelap is home to what many consider some of the most robust reefs in the world, with many large fish, healthy corals, invertebrates and algae (Pinca and Beger, 2002). The excellent reef conditions are largely due to the fact that the area has been devoid of human settlement for several decades due to radioactive contamination and has thus experienced limited resource exploitation. In the 1950s, the population was forced to abandon the atoll and relocate following a hydrogen bomb test conducted by the U.S. military. Shortly after detonation, a change in wind direction caused a cloud of radioactive ash and debris to settle over the island (Niedenthal, 2001). In 1998, a resettlement program was initiated and today the displaced Rongelapese are preparing to return to their native home.

Rongelap Atoll local government (Ralgov) aims to manage their natural resources proactively and requested baseline surveys of Rongelap's reef resources be conducted by staff and students of the CMI Marine Science department before active resettlement beings. NRAS conducted these surveys from 2002-2003. In 2002, 14 sites around Rongelap Island were surveyed. In 2003, 30 sites were surveyed including 11 lagoonal sites and 19 ocean and pass sites.

The reefs surveyed were found in excellent condition, with a large number of fish, coral, algae and megafauna such as sea turtles, rays and napoleon wrasses were abundant (Table 12.2). The biodiversity and abundance of reef organisms at Rongelap Atoll is extraordinarily high for both fish and coral. One new species of coral, *Acropora rongelapensis* (Richards and Wallace, 2004) was described and has since been located in Majuro, Pohnepei and West Papua (Richards, pers. obs.).

*Table 12.2. Mean species number and mean percent cover ± SE of zooxanthellate scleractinian corals at Rongelap Atoll. Percentage of live corals over total substrate cover; other substrate classes were: dead coral, bedrock, sand, rubble, coralline and fleshy algae, soft corals and sponges. Source: Beger and Pinca, 2003.*

| REGION OF RONGELAP ATOLL | MEAN NUMBER OF SPECIES | STANDARD ERROR | AVERAGE % COVER | STANDARD DEVIATION | MAXIMUM % COVER | MINIMUM % COVER |
|---|---|---|---|---|---|---|
| East ocean | 67.3 | 6.3 | 26.4 | 11.52 | 38.08 | 8.75 |
| South ocean | 61.9 | 3.6 | 47.3 | 7.64 | 54.92 | 37.17 |
| West ocean | 71.4 | 3.4 | 59.2 | 5.77 | 63.25 | 55.08 |
| North ocean | - | - | 42.4 | 4.43 | 46.08 | 37.50 |
| East lagoon | 55 | 4.7 | 21.1 | 10.13 | 34.83 | 5 |
| Central pinnacles | 53.6 | 7.7 | 36.7 | 13.49 | 65.00 | 23.75 |
| West pass | 75.3 | 4.4 | 52.8 | - | 52.75 | - |

The pinnacle in front of Enewetak Island and the northwest corner of Rongelap displayed some the highest coral cover in the area (Pinca et al., 2004). Data indicated that branching forms of *Acropora* (e.g., *Acropora loisetteae*) dominates the Eastern lagoon, while *Porites* spp. is more dominant near the West pass (Pinca et al., 2004b). The survey also resulted in range extensions for seven coral species that had not previously been observed in the Marshall Islands. Specimens were collected and are housed at the Museum of Tropical Queensland.

- ***Acanthastrea brevis:*** Small colonies of this species were observed growing near Rongelap. *A. brevis* is considered a rare species and has previously been recorded in areas of Southeast Asia, the West Indian Ocean and Red Sea (Pinca, 2003).
- ***Coscinarea monile:*** This encrusting coral was recorded in both the lagoonal and wall sites at Rongelap. This species is common in the western Indian Ocean, but not in Southeast Asia. All colonies exhibited a uniform brown color and smooth surface (Pinca, 2003).

- ***Seriatopora dentritica:*** Previously only recorded in parts of Southeast Asia, this compact, bushy coral exhibits very fine, delicate branching patterns. One adult colony was observed at a wall location. This species has never before been recorded in the Central Pacific (Pinca, 2003).
- ***Montastrea salebrosa:*** Normally this coral grows as large spherical colonies, but at Rongelap the colony was encrusting with free margins. Known to grow in Southeast Asia, the GBR and western parts of the Pacific, *M. salebrosa* is considered rare (Pinca, 2003).
- ***Acropora loisetteae***: Generally this species has an open branching growth form, but at Rongelap, the colonies found at one site in the lagoon had more of an arborescent table growth form. Rarely mentioned in scientific literature, little is known about its variability (Pinca, 2003).
- ***Acropora nana:*** *A. nana* is a corymbose species with very slender, upright and non-tapering branches. Colonies were commonly observed along the shallow reef edges of Rongelap's exposed wall, as well as at other southern island sites (Pinca, 2003).
- ***Acropora speciosa***: *A. speciosa* grows as a side-attached plate with fusing horizontal branches which give off tapering vertical branches. This coral was observed in small numbers at both lagoonal and wall habitats. *A. speciosa* has been recorded in SE Asia, PNG, the GBR and Fiji (Pinca, 2003).

The monitoring sites with the highest coral cover were located at a pinnacle in front of Enewetak Island (65%) and on the northwest corner of Rongelap Atoll (63%). Both sites were located on the leeward side of the atoll with respect to the prevalent winds. The lowest coral coverage was recorded on the leeward lagoon side, in front of Mellu Island (northeast of the atoll), where the general topography is a steep sand slope with sparse coral patch reefs.

The number of coral species at each site varied from 34 to 90 with an average of 67 (± 13.6) corals. Sheltered sites in the lagoon tended to support fewer coral species and lower cover, but harbored many unusual species, and site variation within the lagoon was greater than in outside areas. The highest species richness was found at sites along the southern and eastern fore reefs and at the west pass.

No sign of coral bleaching was recorded at Rongelap. No coral diseases have been recorded either, and only nine COTS were encountered during the survey period. Some human impacts were noted in the form of marine debris. Longlines were found entangled on corals at four sites in Rongelap and on outer reefs on the leeward (south and southwest) side of the atoll at a depth of 25-30 m.

## NRAS Bikini Atoll Assessment (2002)

Bikini Atoll is one of the most northerly atolls and includes 23 islands and 187 km$^2$ of reef. Reef habitats at Bikini atoll include narrow fringing reef with spur and groove development, reef crest and steep vertical exposed walls, and protected sandy lagoons with patch reef development and inter-reefal fauna (Pinca and Beger, 2002). A total of 183 species of scleractinian coral were recorded from 19 sites at Bikini Atoll in 2002 (Richards et al., in press). Table 12.3 details live coral cover at six biogeographic zones.

*Table 12.3. Coral percent cover in Bikini atoll. Other substrate classes were: dead coral, bedrock, sand, rubble, algae and sponges. Source: S. Pinca, unpub. data.*

| REGIONS IN THE ATOLL | MAXIMUM % COVER | MINIMUM % COVER | AVERAGE % COVER | STANDARD DEVIATION |
|---|---|---|---|---|
| Lagoon East | 57.33 | 8.50 | 35.02 | 24.34 |
| Lagoon north | 64.00 | 16.03 | 40.61 | 25.06 |
| Lagoon South | na | na | 6.03 | 6.03 |
| Ocean East | 38.00 | 7.67 | 23.25 | 15.18 |
| Ocean South | 27.12 | 16.61 | 21.87 | 7.43 |
| Pass | na | na | 27.53 | 27.53 |

As described in detail by Richards et al. (in press), this atoll has been subject to considerable exposure to radioactive nuclear material. Between 1946 and 1958, 23 tests were conducted at seven test sites located on the reef, at the water surface in deep and shallow areas, in the air and underwater for a combined explosive yield of 76.3 megatons. These tests resulted in the creation of five craters up to 73 m deep (Noshkin et al., 1997b) and alteration of natural sediment movement patterns (Noshkin et al., 1997a). The most highly publicized of the Bikini tests, nicknamed "Bravo", involved the detonation of a 15 megaton hydrogen bomb on a shallow fringing reef in 1954 (Niedenthal, 2001). It obliterated three islands and sent millions of tons of sand, coral, plant and sea life from Bikini's reef into the atmosphere. The Bikini lagoon sediment regime was fundamentally altered by the nuclear events due to the pulverization and subsequent resuspension of millions of tons of sediment that are transported and deposited throughout the lagoon to this day. Since the nuclear testing, impacts from pollution and tourism are presumed to have been virtually non-existent in RMI's uninhabited northern atolls, however, the threat of illegal fishing persists.

## NRAS Mili Atoll Assessment (2003)

Mili Atoll is one of the most southern atolls in the Ratak Chain and supports a population of more than 800 people spread among 92 islands comprising 16 km$^2$ (6.15 mi$^2$) of land. In June and July of 2003, REAs were conducted at 20 sites around Mili. The surveys were requested by local landowners and political leaders to support their efforts to establish a marine sanctuary and research station in the northeastern portion of the atoll (Beger and Pinca, 2003). With the assistance of CMI, NRAS baseline data was collected to help determine the optimal location for a marine reserve. These data will also provide a basis for future monitoring programs and facilitate comparisons with reefs in other parts of the country and region.

A total of 20 sites were sampled during a two week period; nine dive sites were located on the ocean side of the atoll, one dive site was located in the South Pass and nine sites were surveyed in the lagoon and pinnacles (Beger and Pinca, 2003). The survey sites were selected to be representative of subregions (habitat areas) that experience environmental variation related to geographical location and degree of exposure to wind and waves (Beger and Pinca, 2003). These regions are: north ocean, west ocean, south ocean, south pass, south pinnacles and north lagoon areas.

Mili's reefs were found to be in excellent condition, with an abundance of fish, coral, algae and other species. The monitoring sites with the highest coral cover were located at two west lagoon sites (53 and 57%). Both sites were located on the leeward side with respect the prevalent winds. High coral cover was also found at sites in the north, west and southern ocean regions. Remaining regions showed a high proportion of sand (Beger and Pinca, 2003). The lowest coral cover was recorded on the leeward ocean side (north of the atoll). Non-*Acroporid* branching corals were represented with the highest relative coverage in the lagoon, as well as the pinnacle areas whereas Non-acroporid encrusting corals dominated the ocean sites (Beger and Pinca, 2003). Overall, the most frequently occurring coral was *Isopora palifera/cuneata*. Coral cover for six biogeographic zones is listed in Table 12.4.

*Table 12.4. Coral percent cover in Mili. Other substrate classes were dead coral, bedrock, sand, rubble, coralline and fleshy algae, soft corals and sponges. Source: Beger and Pinca, 2003.*

| REGIONS IN THE ATOLL | MAXIMUM % COVER | MINIMUM % COVER | AVERAGE % COVER | STANDARD DEVIATION |
|---|---|---|---|---|
| North ocean | 51.50 | 23.33 | 40.13 | 10.02 |
| West ocean | 56.74 | 53.00 | 54.87 | 2.64 |
| South ocean | 40.33 | 35.67 | 38.00 | 3.30 |
| South pass | 11.67 | - | 11.67 | 0 |
| South pinnacles | 16.00 | 8.67 | 12.33 | 5.19 |
| North lagoon | 30.00 | 5.00 | 18.08 | 8.74 |

The number of coral species present at each site ranged from 44 to 72 with an average of 50 corals (±10.3; Beger and Pinca, 2003). Lagoon areas tended to support a higher number of corals, as well as many unique species. Additionally, northern ocean areas supported a high number of corals, while in southern ocean sites fewer coral species were documented (Beger and Pinca, 2003). Lagoon and ocean sites proved to be the most diverse.

No sign of coral bleaching was recorded for the atoll of Mili. No coral diseases have been recorded and only four COTS were found. No anthropogenic impacts were recorded in Mili.

The lowest (14%) cover in fleshy seaweeds was found at the western ocean sites as well, where the highest cover of coralline algae was recorded.

### NRAS Namu Atoll Assessment (2004)

Namu atoll is made up of 54 islets located in the west Ralik chain and is home to approximately 800 people, distributed primarily among the main islands of Namu, Majikin, Mae, Loen. In December 2004, 21 sites were surveyed as part of a NRAS assessment: eight sites were located within the lagoon, two were at passes and 11 were on the ocean side. The eastern and northern sides of Namu were not surveyed for logistical reasons. Sites were grouped into five zones according to their location and general characteristics of topography and substrate. These included sites located in the northern part of the lagoon, two pinnacles surveyed in the northern part of the lagoon, fore reef sites of the western side of Namu, the fore reef area at the very south of the atoll around Len island and sites at the two passes, one in the north (Bok passage) and one to the southwest (Anil passage).

Namu Atoll is peculiar because of the narrow shape of its lagoon and the presence of passes only on the west site which makes the lagoon a relatively closed environment with little circulation. The biological characteristics of this atoll are:

- A very high abundance of alga *Microdyction* in the lagoon and north-western ocean walls
- High abundance of fish and sharks, (which were found in deeper water than at other atolls)
- A high presence of Stylasteridae on the ocean walls
- A high concentration of *Heliopora coerulea* and *Isopora* sp. in the upper reef and reef flat of the ocean side
- Presence of *Millepora* of peculiar shape in high columns both off the walls as well as on pinnacles and
- A high abundance of very large sea fans (*Melithaea*) in the passes.

Total relative cover of live coral was highest at the south fore reef of Namu (Ocean South) and ocean west (Ocean West) sites (Table 12.5). The two passes showed higher cover of corals than lagoon sites, which were particularly low in coral. Here most of the coral surface was covered by algae, especially *Microdyction*. Along the reef, the abundance of live corals decreased with depth from an average of 33% to 24% while the relative abundance of algae increased from 28 to 37 %. In the lagoon, the few sloping patches of corals near the islands supported fewer coral species and several had small patches of white tissue, probably resulting from COTS predation. A large area of bedrock was also found to be densely covered by the alga *Microdyction* as well as many sponges, primarily chandeliers sponges of the genus *Callyspongia*.

*Table 12.5. Coral percent cover in Namu atoll; other substrate classes were: dead coral, bedrock, sand, rubble, coralline and fleshy algae, soft corals and sponges. Source: S. Pinca, unpub. data.*

| REGIONS IN THE ATOLL | MAXIMUM % COVER | MINIMUM % COVER | AVERAGE % COVER | STANDARD DEVIATION |
|---|---|---|---|---|
| Lagoon North | 23.18 | 7.50 | 16.94 | 5.82 |
| Lagoon Pinancles | 20.00 | 1.67 | 13.78 | 10.49 |
| Pass | 24.33 | 22.13 | 23.23 | 1.56 |
| Ocean West | 65.67 | 18.33 | 35.28 | 15.82 |
| Ocean South | 58.33 | 43.00 | 50.67 | 10.84 |

The few lagoon pinnacles at Namu host some large massive corals (*Lobophyllia* sp.) in deep water, many colonies of *Seriatopora hystrix* and *Stylophora pistillata* and small massive *Porites* sp. In shallow water, the diversity of corals is much higher and includes large colonies of massive *Porites*, *Caphophillia*, and the soft coral *Rumphella*, but also bare rock. Namu supports a high abundance of *Millepora*, which forms high columns and complicated structures, as well as *Isopora*, large blue coral (*Heliopora coerulea*), *Astreopora*, massive *Porites*, *Pavona*, Faviids and many Stylasteridae. The two sites at the north pass (Bok passage) and at Anil passage in the south, were similar in appearance: both contained numerous shallow *Isopora* and *Heliopora coerulea* colonies with a dominance of massive *Porites* at deeper layers. Soft corals are abundant in both channels with small white *Dendronephtya* and *Ruphella*, and many small and large sea fans (*Gorgonians Melithaea* sp.) and *Lobophyton* all along the profile between 15 and 30 m, there are spectacular large gardens of *Melithea* and *Junceella* interspersed with giant sponges (*Xestospongia*).

The wall to the west side of Namu atoll is very rich in corals, and its appearance does not change much from north to south. Rock encrusted with *Lithothamnion* (a coralline alga) dominates the reef crest and upper reef of the northern sites, along with abundant *Isopora*, *Millepora* and the highest diversity of corals. Blue coral (*H. coerulea*) are abundant at the upper slope and crest, as well as inside the deep gullies where they compete for space with species of Stylasteridae.

The slope is densely colonized by *Porites* at 15-20 m, with large valleys or gullies and massive coral colonies, giving a complicated topography to the reef. The deep spurs and grooves, usually found on the windward side of atolls, are common on this leeward side in Namu. The wall is fairly steep and below 20 m only rare corals are found. Abundant *Lobophyton* is found around 15-20 m and *Rumpella* sp. can be found below 25 m. The wall becomes more vertical at 30-35 m with large *Melithea* and some foliose corals. In the southern outer reef, the coral cover is dominated in the shallow reef flat (5-10 m) by *Acropora*, *Isopora* and coralline algae (*Goniastrea*, massive *Hydnophora*, *Turbinaria*, large colonies of *Pocillopora damicornis*, *Stylasterina*, *H. coerulea)*. At 12-14 m, the reef is composed of many *Acropora* spp., small *Pocillopora* and lots of coralline algae. The upper reef slope is dominated by very large massive colonies of *Porites* and *H. coerulea*. The wall starts at 18-20 m and deeper parts of the wall are sparsely colonized by rare corals and small colonies of massive *Porites*.

## NRAS Majuro Atoll Assessment (2004)

Home to nearly half of RMI's population, Majuro Atoll is the political and economic capital of RMI and is situated in the southern portion of the Ratak Chain. The coral reefs surrounding this heavily populated atoll suffer impacts from environmental and anthropogenic stressors like marine debris, terrestrial runoff, pollution and overexploitation more than reefs of the outer islands.

In 2004, 16 sites around Majuro atoll were surveyed according to standard NRAS survey protocols. Notwithstanding the high population (20,000 people), numerous construction and development activities, and the presence of more than 5,000 cars, Majuro atoll still contains healthy and diverse coral reefs at some sites. The most impacted parts of the atoll are the nearshore lagoon adjacent to the downtown area, called DUD (Darrit, Uliga, Delap) and sections of the southern coast, where heavy dredging has removed reef structure, increased siltation and sedimentation, changed water circulation patterns, and increased erosion. However, survey sites on the ocean side of the atoll generally contained high live coral cover and relatively high coral species diversity.

*Table 12.6. Coral percent cover in Majuro. Other substrate classes were: dead coral, bedrock, sand, rubble, coralline and fleshy algae, soft corals and sponges. Source: Pinca, 2005.*

| REGIONS IN THE ATOLL | MAXIMUM % COVER | MINIMUM % COVER | AVERAGE % COVER | STANDARD DEVIATION |
|---|---|---|---|---|
| Northeast lagoon | 70.0 | 18.7 | 44.3 | 36.3 |
| Northwest lagoon | 55.0 | 42.5 | 48.5 | 9.2 |
| Southeast lagoon | NA | NA | 51.0 | NA |
| Central pinnacles (lagoon) | NA | NA | 73.0 | NA |
| East ocean | 59.7 | 58.33 | 59.0 | 0.9 |
| North ocean | 64.3 | 52.3 | 57.6 | 6.0 |
| South ocean | 78.5 | 17.7 | 45.3 | 26.9 |

The sites with the highest coral cover included one site on a central pinnacle (where *Porites rus* formed enormous monospecific stands) and the fore reef sites on the east and north sides of Majuro atoll (Table 12.6). The highest abundance of dead coral was found at the southeast lagoon site near the airport. This area has degraded rapidly in the past 4-5 years due to shallow bleaching of the reef flat in the years 2002 and 2003, dredging associated with the construction of an airport hangar and other coral mining activities. Coral diversity and cover declined and the abundance of fish diminished over these few years (S. Pinca, pers. obs.). Dredging continues to occur at the present time. The substrate composition changes with increasing depth along the shelf. Live coral becomes rare with depth while sand, bedrock and algae increase in abundance. Areas of high live coral cover and species richness are located on the reef flat and reef crest.

Overall coral diversity on Majuro is low, with many sites having only six genera represented by less than 20 species. *Porites rus* is one of the most common corals found in the area. *P. rus*, which is rare or absent on a number of remote atolls, is dramatically increasing its dominance on Majuro, particularly since it thrives in disturbed environments. This assertion is also supported by distribution patterns seen at Arno atoll. Along the western shoreline, where conditions are good, *P. rus* only grows in the blast-disturbed anchorage near the fishing jetty.

In many lagoon sites, non-*Acropora* corals (especially three species of *Porites*) prevail over *Acropora* corals, except in some parts of the outer reefs where branching and table *Acropora* and *Isopora cuneata/palifera* colonies are present in high numbers and constitute more than half of the coral population (Figure 12.16). The large *Acropora* tables account for less cover in the lagoon and at pinnacle sites. *Acropora* were found to become less abundant as depth increased, a trend not observed for non-*Acropora* corals.

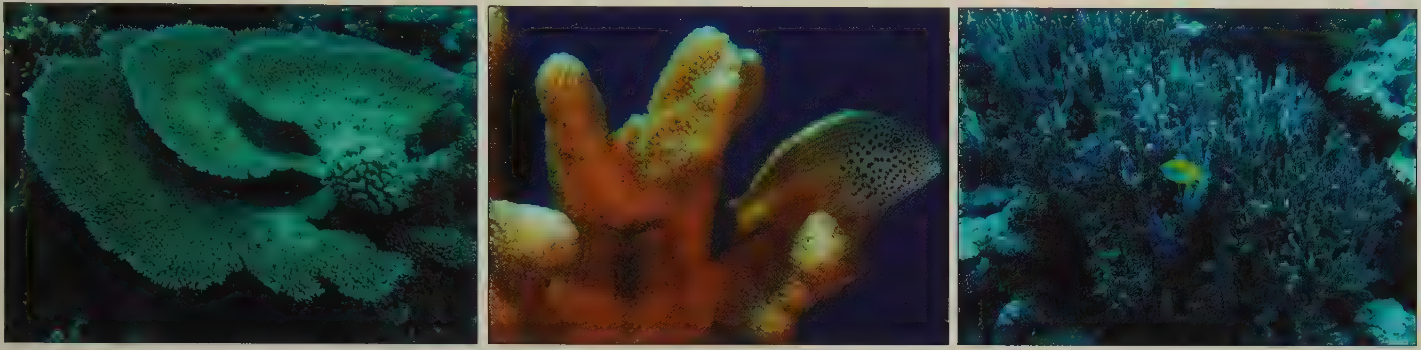


*Figure 12.16. From left to right:* Acropora clathrata. *Photo B. Matters.* Isopora cuneata *with* Paracirrhites forsteri *in camoflauge. Photo J. Maragos.* Heliopora *dominates on reef fronts. Photo: B. Matters.*

No sign of coral bleaching was recorded during surveys in 2005. However, several COTS were recorded at the eastern part of the lagoon, and corals observed there were brittle and often covered in *Dictyota*. Although *P. rus* was the dominant species, several pockets of high species richness were found inside the lagoon and at some outer slope sites. These pockets supported abundant and healthy populations of *Pocillopora* sp. (in the southern lagoon area and near the airport parking lot), *Seriatopora histrix*, *Porites cylindrica*, *Pachyseris speciosa*, *Goniopora, Montipora* and *Scaphopyllia.*

The reefs of the northwest lagoon are singularly diverse, including large plate and foliose colonies of *Echinopora*, *Echinophyllia*, *Pachyseris*, *Pavona* and *Leptoseris*. Smaller massive and encrusting colonies such as *Faviids*, *Goniastrea*, *Astreopora*, *Merulina*, *Scapophyllia*, *Platygyra*, are spectacularly abundant. Large colonies of *Lobophyllia* are abundant, and species that are relatively rare elsewhere are regularly encountered. At least 24 genera were found in a single 25 m belt transect. The northwest lagoon site is the only known lagoon location where an algae that dominates at outer atolls, *Microdictyon*, is abundant. Unfortunately, these once-healthy reefs have suffered high levels of COTS predation since 2005 which has resulted in considerable colony mortality.

Sites along the eastern coast from Rita to Delap point were very healthy and rich in both corals and fish, which makes this area popular with sport divers. The reef flat and slope present full coral coverage with very large table *Acropora* and *Pocillopora* colonies down to about 15 m. Deeper than 15 m (Figure 12.17), bedrock and dead corals make up the substrate, along with healthy smaller table corals, colonies of *Pavona*, *Montipora*, large colonies of *Goniopora* and some soft corals (e.g., *Lobophytum*). The northern outer reef outside of Kolal-en pass is a beautiful and healthy area and is known by tourists as "The Riviera". The reef flat near Kolal-en is very wide and drops off gradually along a gentle slope with very high live coral cover until it reaches a drop off at 15-18 m. Only a few live corals are found deeper than 20 m. Many *Acropora*

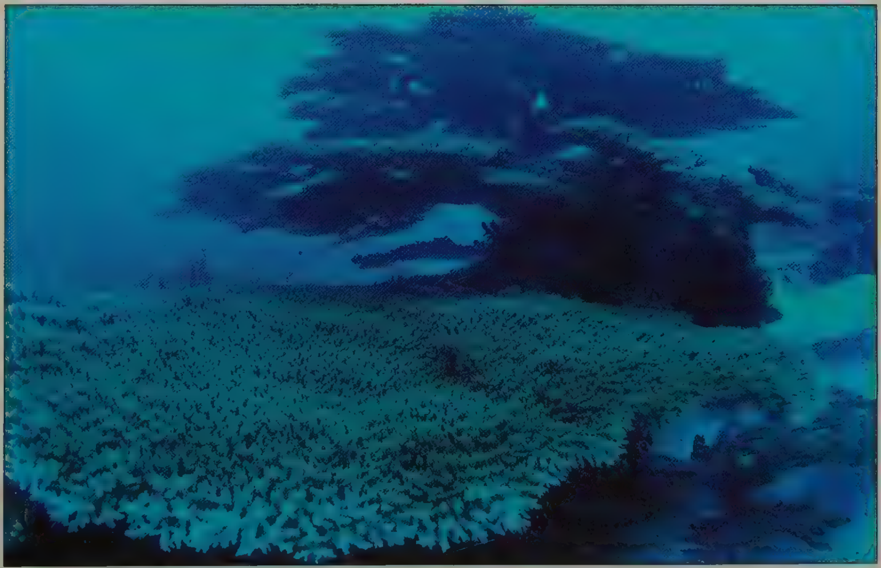


*Figure 12.17. Large table corals, outer reef. Photo: M. Beger.*

corals are found in 10-15 m, along with blue coral (*H. coerulea*), which are replaced at deeper levels by *Porites* cf. *lobata*, *Astreopora* and soft corals (*Sinularia*).

High macroalgal cover was reported at both ocean and lagoon sites. At Majuro atoll, as well as at most other RMI atolls, the populations of macroalgae seem to be in balance with coral. On the other hand, in lagoon areas, the presence of algae is frequently associated with unhealthy conditions. For instance, *Dictyota* has a strong presence at northern lagoon sites, particularly Irooj Island, while *Lyngbia* (filamentous algae) is found in abundance at the southern side (Pinca, 2005). The high presence of these algae may indicate past bleaching events or COTS outbreaks (Pinca, 2005). Among the algae recorded, encrusting coralline algae (*Halimeda* sp.) and blue green algae (cyanobacteria) are overall the most frequently encountered species. *Halimeda* is very common on reefs and is found especially on the slopes and walls at ocean sites. The abundance of *Microdyction*, another very common alga on healthy reefs of RMI, is less at Majuro than at other atolls, where it can cover large areas of substrate both inside and outside the atoll. *Microdyction* and *Halimeda* are separate by depth: *Microdyction* is found at more shallow depths, while *Halimeda* is deeper. Encrusting coralline algae are found throughout the depth range but are more abundant at shallower depths. Other outer reef algae documented include *Peyssonnellia* and a few observations of algae in the genus *Turbinaria*. Other algal genera such as *Tydemania* and *Padina* were common at lagoon sites. The pinnacle showed the least average macroalgal cover. Blue sponges of the genera *Cribochalina* and *Ianthella* were common in the lagoon.

## NRAS Ailuk Atoll Assessment (2006)

Ailuk Atoll is situated in the northeast part of the RMI in the Ratak chain. It is located around 10° 58' N and 169° 88' E. The atoll contains approximately 55 islets and is about 24 km (15 mi) long and 11.3 km (7 mi) wide. It has a land area of 5.3 $km^2$ (2.07 $mi^2$) and a lagoon area of 177.3 $km^2$ (68.47 $mi^2$). The lagoon is deep and is delimited on the east by a rather discontinuous reef scattered with more than 50 closely-spaced islands separated by narrow, shallow channels. The whole of Ailuk atoll has four passes, all of which are located on the west side. From north to south these are Eneman passage, Morok channel, Erappu channel and Enije channel.

The main residential island, Ailuk, is small (about 300 m long and not much wider) and inhabited by about 400 people. Enejelar Island, at the Northern end of Ailuk Atoll, is another populated island where a small group of 40 people live. Ailuk is the only remaining atoll in RMI where outrigger canoes are the main means of transportation. Fishing, transport of copra and pandanus and leisure sailing are all done using traditional locally-built outrigger canoes.

During 2006, a total of 30 survey sites were assessed over the course of 14 days. Survey sites were distributed among geographical, topographical and morphological areas. During data analysis, regions with similar characteristics were grouped into six clusters based on the geographical location, geomorphology and substrate composition of each site. These clusters include lagoon east, lagoon northwest, pinnacles central, pinnacles north, ocean west and passes.

*Figure 12.7. Coral percent cover in Ailuk atoll. Other substrate classes were: dead coral, bedrock, sand, rubble, coralline and fleshy algae, soft corals and sponges. Source: S. Pinca, unpub. data.*

| REGIONS IN THE ATOLL | MAXIMUM % COVER | MINIMUM % COVER | AVERAGE % COVER | STANDARD DEVIATION |
|---|---|---|---|---|
| Pass | 44.50 | 11.67 | 31.17 | 17.26 |
| Ocean west | 53.33 | 32.67 | 44.11 | 7.40 |
| North pinnacle | 39.00 | 21.00 | 31.00 | 9.17 |
| Lagoon north-west | 20.00 | 18.67 | 19.33 | 0.67 |
| Lagoon east | 25.33 | 2.00 | 15.93 | 9.26 |
| Central pinnacles | 50.50 | 20.00 | 35.39 | 10.99 |

Substrate composition was graphically compared among the six groups. The eastern lagoon area was dominated by sand and low live coral cover. Cover of live coral increases from north and western lagoon areas to central pinnacles to northern pinnacles, to western ocean and the passes (Table 12.7). Sites at the central pinnacles, western ocean, and in passes all have live coral cover greater than 40%. Passes A08 and A27 contain areas of high live coral cover, but pass A27 shows a higher abundance of seaweeds compared to the southwest pass (A05). Live coral cover is highest between 15 and 20 m at sites along ocean reefs and at central pinnacles, but at the northern pinnacles and pass sites, live cover peaks in shallower depths. This is a particular feature of the western ocean reef of Ailuk atoll, compared to other atolls where shallow and mid-depth layers tend to have higher live coral cover. At ocean sites, the first 10 m are dominated by bedrock and coralline algae. Cover of macroalgae is higher at ocean and pass sites than in the lagoon and at pinnacles.

Summarizing by major environments (lagoon, pass and ocean wall), sites in the lagoon show a predominance of sand, low cover of bedrock and low cover of coral which increases with depth. Coral cover in the passes is highest in shallow water. Ocean sites have high coral cover that increases with depth, more exposed bedrock and relatively high cover of coralline algae.

Although the entire perimeter of the atoll was not sampled during the surveys at Namu, Ailuk and Rongelap, it is possible to compare the results from ocean sites at these three atolls. Western ocean slopes in Namu and Rongelap had more intricate topography, due to the prevalence of deep spur and groove formations and large coral heads. These areas usually contained greater diversity than the vertical walls common along Ailuk's western reef margin. Nevertheless, regardless of the atoll, areas near pass entrances are the biologically the richest. The *Acropora* gardens found on a pinnacle reef adjacent to a pass at Ailuk were exceptional, and scientists recorded very high fish biomass that included large schools of jacks, snappers, trevallies, coral groupers, eagle rays, tuna, turtles and Napoleon wrasse.

### Rongelap Atoll Long-term Reef Monitoring Program (2006-present)

In December 2006, the initial phase of a long-term monitoring program in Rongelap was completed. Led by M. Beger and Z. Richards and funded by National Oceanic and Atmospheric Administration (NOAA), the British Petroleum Conservation Leadership Programme (http://conservation.bp.com/projects/700204_proj.asp), CMI, The University of Queensland, James Cook University, MIMRA and the Australian Patrolboat program, the project initially established seven permanent monitoring sites in the vicinity of Rongelap Island. Beginning in 2008, project scientists will establish additional sites in more remote parts of the atoll. The program's objectives include documenting trends in the reef community during resettlement of the atoll as detailed in Table 12.8.

*Table 12.8. Rongelap Atoll Long-term monitoring initiative project objectives and details.*

| PROJECT OBJECTIVE | DETAILS |
|---|---|
| Develop monitoring initiative at Rongelap Island to document possible ecosystem changes with resettlement | Monitoring program with nested sites and five replicates: High-settlement island outer reef, lagoon and pass, and controls of remote island outer reef, lagoon and pass |
| Collect baseline data for long-term monitoring program | Add spatial explicit monitoring data of fine resolution to existing data set of Rongelap Reef status (Pinca et al., 2004b); Target sites adjacent to likely sources of impacts, such as main settlements, airport, port, proposed aquaculture venture, proposed piggery |
| Collect data by scientists and trained locals | Scientist monitoring for detailed analysis of population trends; Trained locals (non-scientists/ students) monitoring to allow low-cost continuity of the program on a sustainable and locally funded basis |
| Involve local surveyors trained in CMI's Marine Science Program | People with previous survey experience refresh their skills; Recently trained people can obtain practical skills; Locals from RalGov, MIMRA, EPA and CMI |
| Create database for monitoring to be housed jointly by CMI and MIMRA | Database is accessible and easy to query for future reference; Database is able to also store future data |

In a world in which many reefs have suffered significant recent and ongoing degradation (Jackson et al., 2001), Rongelap represents one of the few reefs in the world still in excellent condition. On local and regional scales, Rongelap Atoll is considered to be an important source of propagules for exploited reefs. This project is intended to provide unique insight into the patterns and processes of both natural and disturbed coral reef ecosystems. Very little is known about how a reef in natural equilibrium responds to human impacts. This project will be one of the first to proactively monitor ecosystem changes and provide data that can be considered during the establishment and implementation of marine reserves. Although marine reserves are a popular approach to reef management (Sladek Nowlis and Roberts, 1999; McClanahan and Mangi, 2000; Roberts et al., 2001), ongoing monitoring is essential for evaluating their success and developing adaptive management strategies. This long-term monitoring project will detect and quantify shifts in reef health that result from increased exploitation, inform the process of marine reserve management and elucidate ecosystem processes.

The Rongelap long-term reef monitoring program collects quantitative data for fishes, mobile invertebrates, benthic cover, and live coral cover and diversity. The condition of coral reefs at the sites was reported as excellent or near excellent, with a small amount of marine debris (soda tins, corrugated iron, fishing rods) observed at some lagoon sites. Monitoring has already revealed a specific change occurring within the past two years: one of the ocean sites next to the airport contained several dead colonies of table corals in the genus *Acropora* that had not previously been detected; since the mortality is restricted to one species, it may indicate the presence of coral disease, but other factors could also be responsible.

Oceanic circulation is important for dispersal of marine species on local, regional and global scales and influences community structures and patterns (Armsworth, 2002). In addition to the biological data discussed above, the Rongelap monitoring program also collects limited climatic and oceanographic data to enable the development of a realistic circulation model for Rongelap Atoll that can be used to simulate larval transport among these remote clusters of atolls that are spatially isolated from continental influences (Peterson et al., 2005; Peterson et al., 2006). Wind speed was measured by installing an anemometer on the Rongelap pier for the duration of the field trip (Figure 12.18). Local tidal information was obtained by placing tide measurement probes both on the lagoon pier and on the ocean side of the atoll to measure tidal differences within and outside the atoll. Rates of flow across the reef flat was obtained by recording the track of a balloon filled with fresh water with a GPS and a depth sounder. Local land height was surveyed using land surveying equipment (Figure 12.18).

Remotely sensed imagery from the ASTER sensor was used to create a bathymetric model of the atoll (ELP, unpub. data). A linear regression model was constructed using subsamples of validation data derived from GPS tracked echo soundings and historic nautical charts to predict depth from the calibrated ASTER data (ELP and Reston, unpub. data).

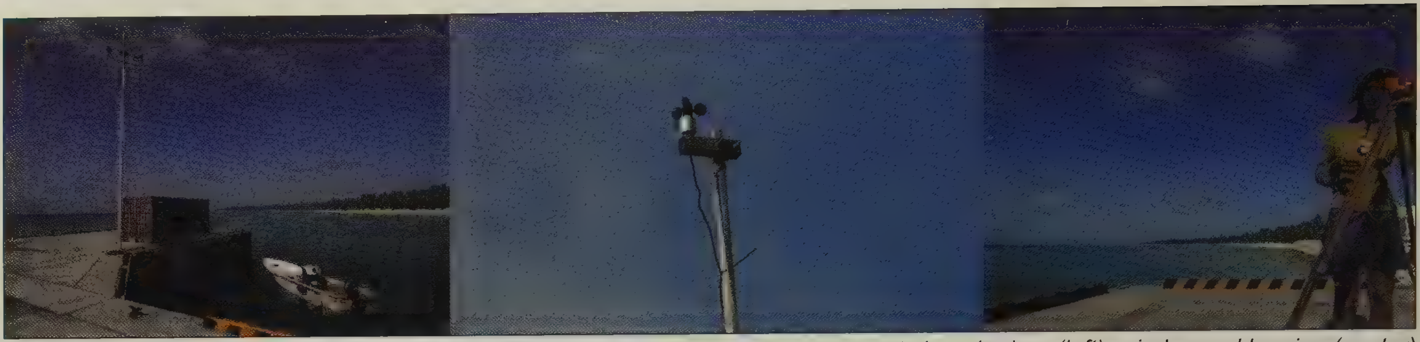


Figure 12.18. Measurement of physical data: drifting across reef flats with instruments in a dry-bag (left), wind speed logging (center) and land height surveying (right). Photos: A Seale.

## CMI Majuro Atoll Long-term Monitoring (2005-2006)

Permanent transects are particularly valuable tools for detecting long-term changes, and are ideal for documenting the gradual ecological degradation experienced by reef ecosystems on Majuro. High resolution photomosaic documentation of transects was initiated on Majuro to document a coral disease outbreak and has since been used to record coral growth and recruitment, document mortality from COTS predation and subsequent recovery, and record damage associated with coastal dredging operations.

Six permanent 50 m transects, two of which are marked by stainless steel, were photographically monitored in 2005 in Majuro lagoon. An additional three transects were established in 2006 near a new reef flat quarry. Resurveys of these sites documented table corals that had been fractured by quarry blasts, which ultimately led to a reduction in blast intensity. Digital video recordings taken during five 1997 Majuro surveys have recently been analyzed and plans to revisit these sites are being made.

A reef flat quarry that was mined in 2001 is being mapped and monitored in great detail (i.e., each coral colony is mapped in a GIS) with the participation of local college students (Jacobson, unpub. data). Documenting reef recovery involves labeling and photographing individual coral colonies from which growth data can be calculated as well as recording information about fish diversity. So far, 30-40 fish species have been observed, compared to only 10 species that were found at a more recently mined reef quarry.

## Ailinginae Atoll Assessment

Ailinginae Atoll (11° N, 167° E) is one of the world's few uninhabited and complete atoll ecosystems, and numerous globally depleted species, including giant clams (*Tridacna gigas, Hippopus hippopus*), brown booby (*Sula leucogaster*), sharks, groupers, bumphead parrotfish (*Bolbometapon muricatum*), napoleon wrasses (*Cheilinus undulatus*), coconut crabs (*Birgus latro*) and resident dolphins can be found in abundance. Although little information was available to characterize the distribution of habitats or to identify areas of particular biological importance that warrant special protection, in 2005, the RMI began a process to nominate Ailinginae and Bikini Atolls for World Heritage consideration. The formal nominations are expected to be submitted to UNESCO in 2009.

A comprehensive natural resource assessment for Ailinginae atoll was recently undertaken to address existing information gaps and support the nomination of Ailinginae Atoll to the World Heritage List. The project integrated field survey data collected at 45 sites around Ailinginae Atoll during 2002 and 2007 with habitat information derived from high resolution multispectral satellite imagery. Through the application of geospatial tools and the software program MARXAN, a simulated annealing algorithm with a GIS interface, the assessment identified areas of high biological importance within the atoll and prioritized conservation areas based on species and habitat diversity, presence of rare, depleted or endangered species, and nesting habitat for seabirds and sea turtles. The outputs of this research are being delivered to UNESCO World Heritage Centre and the government of the RMI as baseline information about Ailinginae's resources. The data are also being used in the development of an adaptive management plan compatible with limited extractive use by the residents of Rongelap, the neighboring atoll, and future eco-tourism plans for both Rongelap and Ailinginae.

## Secretariat of the Pacific Community Atoll Assessments (2007)

Four atolls, Ailuk, Likiep, Majuro and Arno, were assessed by scientists from the Secretariat of the Pacific Community to determine the abundance and distribution of commercial fish and invertebrate species. At the same time, an assessment of reef health and substrate composition was completed. No results were available for inclusion in this report.

# ASSOCIATED BIOLOGICAL COMMUNITIES

## *Natural Resources Assessment Surveys (NRAS)*

NRAS-Conservation surveys conducted in conjunction with the CMI and MIMRA began efforts to document the status of RMI reef ecosystems in 2001. NRAS expeditions comprising a team of 9-10 international and local Marshallese scientists surveyed reef habitats at Likiep (2001), Bikini (2002), Rongelap (2002-2003), Mili (2003), Namu (2004), Majuro (2004) and Ailuk (2006). The NRAS surveys include baseline data on fish, sharks, corals, invertebrates and marine algae and summary information is available at: http://www.nras-conservation.org.

### *Methods*

The methods used to survey populations of living marine resources are part of a standard suite of methods discussed in the Benthic Habitat section. Simultaneously with collection of data on coral, macroalgae and other substrate/ cover types, data on fish and invertebrates was collected along four 50 m transects located at predetermined depths. Surveyors recorded the presence and abundance of target fish species, which were selected based on their value to both the commercial food and aquariums trades, within a 5 x 50 m belt transect (survey dimensions include 2.5 m on either side of the tape, to a height of 5 m from the benthos, and a forward distance of 5 m). Observed fish were identified to family or to species when possible. Invertebrate data were collected by counting organisms located within 2.5 m on either side of the 50 m transect line.

Fish species richness was also assessed during timed swims in depths ranging from 0 to 30 m. Sharks, rays, napoleon wrasses, giant trevallies, and turtles were assessed on timed swims. These species were counted, sexed where applicable, and the depth at which they were first encountered was recorded. The presence of these species was also recorded opportunistically by all surveyors during other activities.

### *Results and Discussion*

### Rongelap Atoll

A total of 397 fish species were recorded at Rongelap in 2003 (Beger and Pinca, 2003). The number of fish species at each site varied from 91 to 205. On average sites harbored 124 (±32.4) species of fish. Sheltered sites in the lagoon tended to support less fishes in total, but they harbored many unusual species, and site variation within the lagoon was greater than in outside areas. The highest fish diversity was recorded at Jabwan point, an area which is in particularly good condition (Pinca et al., 2004b). High fish diversity values were also observed at the lagoon side of Rongelap and in the northeastern part of the atoll around Enebarbar Pass (Pinca et al., 2004b). Passes generally supported more species of fishes due to their higher habitat diversity and the strong currents that flush the passes and transport nutrients.

The highest fish abundance was documented at sites in the east lagoon and at west ocean reefs. The most abundant food-fish families included surgeonfish (Acanthuridae), wrasses (Labridae), snappers (Lutjanidae) and groupers (Serranidae; Pinca et al., 2004; Figure 12.19). Large black and white snappers were the most frequently sighted fish and were often seen swimming in large schools. Giant coral groupers (*Plectropomus laevis*) and the brown-marbled grouper were notably bigger and more abundant than at atolls where fishing is more prevalent (Pinca et al., 2004). Overall, surgeonfish were the most abundant family, particularly at lagoon and ocean sites (Pinca et al., 2004b).

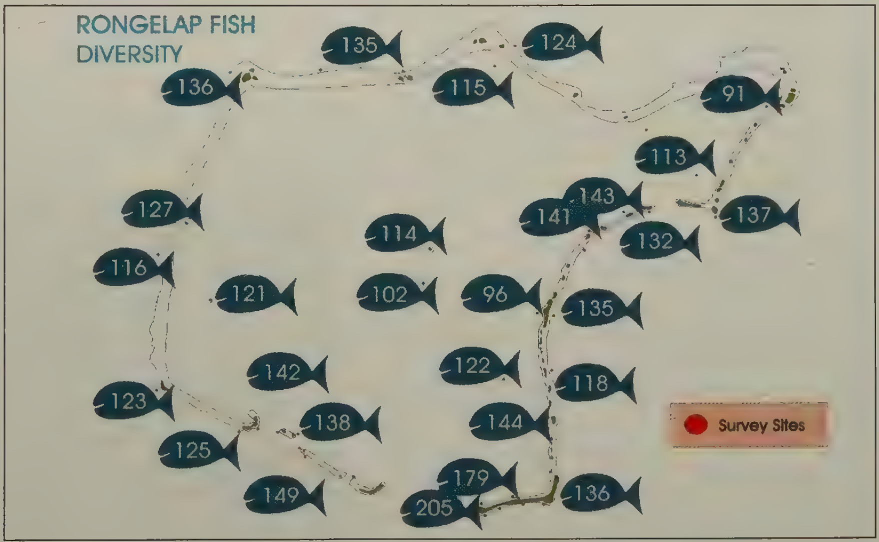


*Figure 12.19. Fish species richness from single timed swims at Rongelap survey sites. Source: Beger and Pinca, 2003.*

Given their ecological importance and popularity with tourists, megafauna such as sharks and Napoleon wrasse deserve special attention, although they are not yet protected in the RMI. Reefs at Rongelap Atoll are populated by several species of reef sharks, including white tip sharps, zebra sharks, gray reef sharks and nurse sharks (Pinca et al., 2004b). Their presence is threatened by a growing shark fishing trade. Shark fins continue to be exported from Majuro, allegedly sourced from long line tuna bycatch. Sharks were counted on timed fish swims. Table 12.9 shows that mean abundance values for reef sharks varied between species and locations in Rongelap Atoll. Grey reef sharks (*Carcharhinus amblyrhynchos*) were the most abundant shark species observed at Rongelap Atoll, particularly on the northern ocean side of the atoll. Blacktip (*Carcharhinus melanopterus*) and whitetip reef sharks (*Triaenodon obesus*) were observed in each zone. Silvertip sharks (*Carcharhinus albimarginatus*) were rarely seen, and all sightings occurred on deep drop-offs on the eastern ocean side or at the central pinnacles. Nurse sharks (*Nebrius ferrugineus*) appeared to be rare and were only seen at three sites: two central pinnacles and one western ocean site.

Table 12.9. Abundance of sharks in seven habitat zones at Rongelap Atoll. Source: Beger and Pinca, 2003.

| | GREY REEF SHARK | | BLACKTIP REEF SHARK | | WHITETIP REEF SHARK | | SILVERTIP SHARK | | NURSE SHARK | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Mean Abundance | SD | Mean Abundance | SD | Mean Abundance | SD | Mean Abundance | SD | Mean Abundance | SD |
| East Ocean | 5.2 | ± 5.45 | 0.4 | ± 0.55 | 0.4 | ± 0.55 | 1.0 | ± 1.41 | 0.0 | ± 0.00 |
| South Ocean | 5.6 | ± 7.83 | 0.4 | ± 0.89 | 1.4 | ± 1.67 | 0.0 | ± 0.00 | 0.0 | ± 0.00 |
| West Ocean | 6.0 | ± 8.49 | 0.0 | ± 0.00 | 0.5 | ± 0.71 | 0.0 | ± 0.00 | 0.5 | ± 0.71 |
| North Ocean | 10.7 | ± 5.51 | 0.3 | ± 0.58 | 0.3 | ± 0.58 | 0.0 | ± 0.00 | 0.0 | ± 0.00 |
| East Lagoon | 3.0 | ± 2.16 | 0.3 | ± 0.49 | 0.9 | ± 0.69 | 0.0 | ± 0.00 | 0.0 | ± 0.00 |
| Central Pinnacles | 7.9 | ± 6.47 | 1.0 | ± 1.29 | 1.0 | ± 0.82 | 0.1 | ± 0.38 | 0.3 | ± 0.11 |
| West Pass | 6.0 | ± 0.00 | 1.0 | ± 0.00 | 1.0 | ± 0.00 | 0.0 | ± 0.00 | 0.0 | ± 0.00 |

Napoleon wrasses (*Cheilinus undulatus*), a large proportion of which are juveniles, continue to be commercially fished on a small scale for consumption in local restaurants, although one market has banned their sale. An adult can be sold to a local resort restaurant for $200, a strong financial incentive. In 2000-2002, hundreds of Napoleon wrasse were captured for export to Asia in Maleolap, Likiep, Ujelang, Mili, Ailuk and other atolls. During surveys, *C. undulatus* were mainly observed in the eastern part of Rongelap Atoll (Figure 12.20), where they were found at the edge of the drop-off, on lagoon pinnacles near passes and in passes.

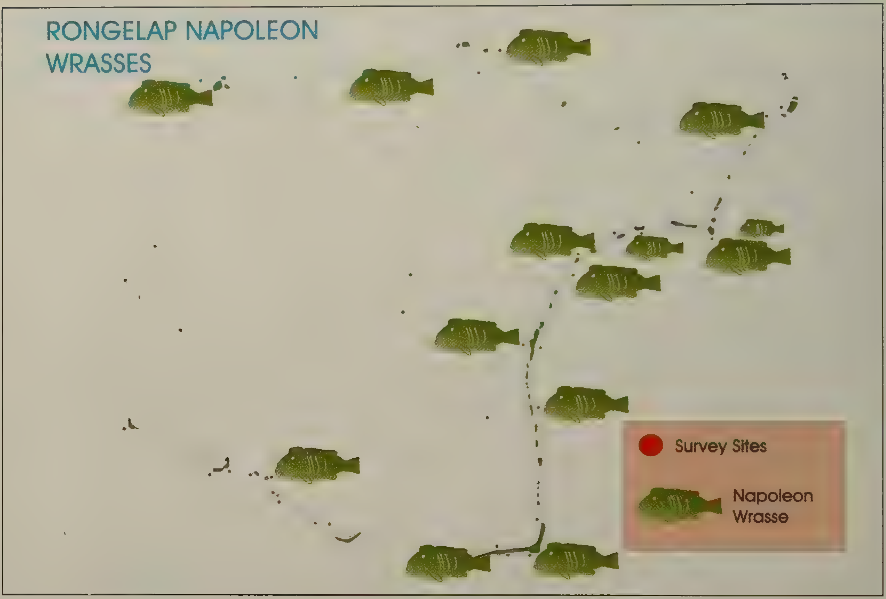


*Figure 12.20. Occurrences of Humphead wrasses at Rongelap Atoll. Smaller icons signify locations where juveniles were seen. Source: Beger and Pinca, 2003.*

Although some species of giant clam (particularly *Tridacna gigas*) are becoming rarer in RMI waters, this is not the case at Rongelap (Figure 12.21). In 2003 four species of giant clam (*T. maxima*, *T. gigas*, *T. squamosa*, and *Hippopus hippopus*) were found in the area (Beger and Pinca, 2003; Pinca et al., 2004b).

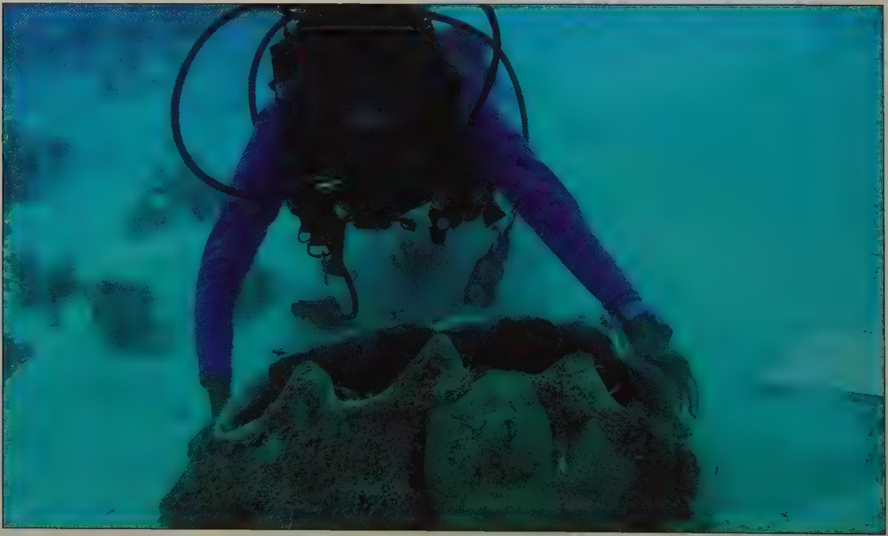


*Figure 12.21. A local surveyor is measuring a* Tridacna gigas *(Giant clam) in the lagoon. Photo M. Beger.*

## Mili Atoll

A total of 373 fish species were recorded at Milli Atoll during the 2003 assessment, with the number of fish species at each site varying from 95 to 162 with and average of 124 (±15.9; Beger and Pinca, 2003). Areas sheltered from wave and wind exposure, like the lagoon, tended to support fewer fish, but contained many uncommon species. The central pinnacles in the southern lagoon and ocean areas proved to be the most diverse. Even fish species targeted by fisheries were abundant and included large individuals, as were megafauna such as sea turtles, whales, and rays. Sharks, however, were not very abundant, and there was local anecdotal evidence of illegal shark fishing by foreign fishing operations. In Mili Atoll, all shark species were relatively seldom encountered, which was in sharp contrast with some of the northern Atolls such as Rongelap and Bikini (Beger, unpub. data). Humphead wrasses, on the other hand, were encountered during each dive (Pinca et al. 2004a). Most were seen in the northern regions of the atoll.

The total abundance of fish did not differ dramatically across habitat regions (Beger and Pinca, 2003). Abundance was greatest at the south and north ocean regions. Surgeonfish, wrasse, fusilier, parrotfish, snapper and grouper families were among the important commercial fish families with the highest total number of fish counted (Beger and Pinca, 2003). The highest abundance of surgeon fishes was found at the north lagoon and southern ocean sites. Relative abundance of wrasses peaked at the south pinnacles, while snappers were in greatest abundance at the west and north ocean areas (Beger and Pinca, 2003).

Shark encounters at Mili Atoll were relatively rare. Grey reef sharks, silvertip sharks, and whitetip reef sharks were observed on most ocean zone dives. In general, their abundance varied among habitat regions. The assessment indicates blacktip reef sharks were more frequently observed in the northern ocean zone and on the central southern pinnacles (Beger and Pinca, 2003). Nurse sharks were not observed. It was found that blacktip reef sharks preferred shallow waters about 2 m or less in depth. Silvertip sharks were observed at depths of 15 m or more, indicating a preference for moderate to deeper waters. Table 12.10 shows that mean abundance of reef sharks varied by species and location in Mili Atoll. Grey reef sharks (*Carcharhinus amblyrhynchos*), silvertip sharks (*C. albimarginatus*) and whitetip reef sharks (*Triaenodon obesus*) were seen on most dives in all ocean zones, and their abundance varied between these habitats. Blacktip reef sharks (*C. melanopterus*) were observed in the northern ocean zone and on the central southern pinnacles.

*Table 12.10. Abundance of sharks in six habitat zones at Mili Atoll. Source: Beger and Pinca, 2003.*

| | GREY REEF SHARK | | BLACKTIP REEF SHARK | | WHITETIP REEF SHARK | | SILVERTIP SHARK | |
|---|---|---|---|---|---|---|---|---|
| | Mean Abundance | SD | Mean Abundance | SD | Mean Abundance | SD | Mean Abundance | SD |
| North Ocean | 1.5 | ± 2.3 | 0.3 | ± 0.5 | 0.5 | ± 0.5 | 1.2 | ± 1.5 |
| North Lagoon | 0.1 | ± 0.4 | 0 | ± 0 | 0.6 | ± 0.8 | 0 | ± 0 |
| West Ocean | 0 | ± 0 | 0 | ± 0 | 0.5 | ± 0.7 | 1.5 | ± 2.1 |
| South Ocean | 1.5 | ± 0.7 | 0 | ± 0 | 1 | ± 1.4 | 0.5 | ± 0.7 |
| South Pass | 2 | ± 0 | 0 | ± 0 | 3 | ± 0 | 0 | ± 0 |
| South Central Pinnacles | 0 | ±0 | 1.5 | ± 0.7 | 0.5 | ± 0.7 | 0 | ± 0 |

Four giant clam species were recorded at Mili Atoll. The highest abundance was found at the south pass where eight *T. squamosa* individuals were observed (Pinca et al., 2004a).

## Namu Atoll

At Namu atoll, mean fish abundance varied among sites and reef types. Average fish abundance was highest at the western ocean sites, which were also the sites with high coral cover. Acanthuridae are the most abundant food fish family at Namu overall, and this is probably related to the very high cover of macroalgae at most sites. Acanthurids are mostly abundant at the pinnacles and ocean south sites. Scaridae and Lutjanidae are the next most abundant fish families. Lutjanidae, mainly black and white snappers (*Macolor macularis)*, black snappers (*M. niger)*, humpback snappers (*L. gibbus)* and red snappers (*Lutjanus bohar*) and Serranidae are abundant everywhere in approximately the same proportion. Mullidae and Lethrinidae, especially big eye emperors (*M. grandoculis*) are present in similar numbers everywhere except at the channel. Striped bristle-tooth (*Ctenochaetus striatus*) and white-cheek surgeonfish (*Acanthurus nigricans*) are the most abundant fish at Namu; this is also the case at Majuro. Target fish species such as big nose unicorn-fish (*Naso vlamingii*), big eye emperor-fish (*M. grandoculis*), forktail rabbitfish (*S. argenteus*), peacock groupers (*C. argus*) and giant coral groupers (*P. laevis*) are relatively more abundant in Namu than in Majuro atoll, where the fishing pressure is higher.

Black tip sharks (*Carcharhinus melanopterus*), grey reef sharks (*C. amblyrhyncos*), white tip sharks (*T. obesus*), skates (*Urogymnus africanus*) and spotted eagle rays (*Aetobatus narinari*) were spotted at sites in the north and at the passes. One leopard shark (*Stegastoma varium*) was spotted in shallow water among the gullies. Only one small green turtle was spotted. Some marine debris in the form of fishing lines was found tangled among coral colonies at Namu, indicating that fishing occurs even at sites far from the main human settlement at Maikin.

The total number of giant clams found at Namu's 21 sites is 559, the majority of which are *Tridacna maxima*. The other species found are *T. squamosa*, *T. gigas* and *Hippopus hippopus*. The giant clams were observed primarily at ocean sites, however a few were found in the lagoon and at pinnacles as well. The highest concentration is along the southern ocean side. A total of seven black pearl oysters were counted at the lagoon and channel sites. Sea cucumbers are rather rare, but the most abundant species, *T. ananas*, was found at most sites.

*Microdyction* was present at many of the sites at Namu, especially at northern ocean sites. This alga usually competes with *Halimeda* in other atolls, but it appeared to be decisively dominant in Namu. Coralline algae are more obviously abundant on the ocean side. Sand is the dominant substrate type in the lagoon although some lagoon regions contain numerous scattered patch reefs and pinnacles.

## Majuro Atoll

Majuro's reef fish populations appear to be decreasing all over the atoll, according to opinion surveys conducted among local residents (Ikenoue and Adachi, 2004). However quite a few carnivorous species can be still found around Majuro; sharks and rays as well as green turtles are commonly sighted in the lagoon and near fore reef walls.

Fish populations are subject to pressure from local fishing activities as well as from live collection for the aquarium fish trade. No live food fish harvesting has been focused on Majuro atoll yet. A shark fishing enterprise was active for two years before being discontinued in 2003. Although it had permission to catch only oceanic sharks, there is evidence that reef sharks were targeted as well. Still, sharks were commonly seen during the 2003 NRAS surveys.

The fish population is decreasing all over the atoll, according to the impressions of local people (Ikenoue and Adachi, 2004). However quite a few carnivorous species are still found, and sharks and rays, as well as green turtles are common around the lagoon and off the walls (although shark populations have dropped along the southern shore, as noted above). In addition to food fish (which is caught in thrown nets, set nets, illegal gill nets within the lagoon, on spears and by hook and line) ornamental aquarium fish are also targeted. At least four enterprises are active in this field, diving six days a week.

Common lagoon fish fauna include: parrotfish, many butterfly-fish (especially *Chaetodon auriga*), angelfish *Pygoplites diacanthus*) and bicolor angelfish (*Centropyge bicolor*), titan triggerfish (*Balistoides viridescens*) nesting in the sand, many damselfish, especially *Dascyllus auranus*, but also big-eye emperor-fish (*Monotaxis grandoculis*), spotted eagle rays (*Aetobatis narinari*) and turtles (*Chelonia mydas*); near the pass, large schools of *Carangoides sexfasciauts* and other Carangidae and schools of barracudas; on the other reefs, occasional Napoleon wrasses (*Cheilinus undulatus*, in small school off the reefs of Delap), large schools of convict tangs (*Acanthurus triostegus*), and other surgeonfish like striped bristle-tooth (*Ctenochaetus striatus*, tiebdo), white-cheek surgeons (*Acanthurus nigricans*, *A. olivaceus*), black snappers (*Macolor niger*), rabbit-fish (*Siganus argenteus*), yellow spot emperors (*Gnathodentex aurolineatus*) and Scythe triggers (*Sufflamen bursa*) are common.

Surgeonfish (Acanthuridae) are overall the most abundant family. Their highest abundance is at the ocean sites. Parrotfish (Scaridae) are the second most abundant family, followed by snappers (Lutjanidae) and goatfish (Mullidae). In terms of individual species, striped bristle-tooth surgeons (*Ctenochaetus striatus*) are the most abundant target food-fish, followed by white-cheek surgeons *(Acanthurus nigricans)*, orange-spine unicorns *(Naso lituratus)* and big-eye emperors *(Monotaxis grandoculis*). Black tip sharks (*Carcharhinus melanopterus*), and white tip sharks (*Triaenodon obesus*) are frequent both at the pass and off the southern and eastern walls. Grey reef (*Carcharinhus amblyrhynchos*) sharks were also common, but found in deeper water.

Long-spine sea urchins (*Diadema* spp.) are rarely found. Sea cucumbers were often found at the northern lagoon side. Among the present species, *Telenota ananas* is the most common giant sea cucumbers (*Holothuria anax*). Many *Tridacna maxima* and *T. squamosa* were found on the outer coral crest. A total of 32 giant clams were observed at Majuro representing only two, *Tridacna* maxima and *T. squamosa*, of the five species found throughout RMI. Most were recorded at the ocean sites and some were observed in the waters off Irooj Island on the lagoon side. Towards the west area of Majuro (closer to Arrak) there are several COTS and their scars on corals are visible, as well as concentrations of *Drupella* on *Acropora* corals. Growing numbers of COTS have been observed since the first invasion of Majuro's reefs in 2004 and 2005. The animals were first found off the southwestern part of the atoll and eventually made their way to the north side, the Irooj Island area, and the northwestern regions of Majuro (Pinca, 2005). A large population, made up of 500-1,000 individuals/km of lagoon shoreline, was found for the first time off the southwestern region of the Island. Only four COTS individuals were recorded at the selected survey sites.

## Ailuk Atoll

A total of 258 fish species were recorded from Ailuk ranging from 105 species on a western dropoff to only 65 species at some lagoon sites. This data is not directly comparable with the Rongelap data set, which was collected by a more experienced surveyor. Of the various geographic subregions (lagoon patch reefs, lagoon coastal reefs, passes, outer walls) at Ailuk, the area of highest fish species richness was recorded at outer reef sites and near passes. The size and diversity of apex predators was highest at certain passes (Pinca, 2006). Passes generally have shallow sandy bottoms, interspersed with patch reefs and caves, which creates very complex seafloor topography. Representative pass species included *Lutjanus gibbus*, *Lethrinus nebulosus*, large *Aprion virescens*, *Haemulids*, *Chlorurus microrhinos*, several *Gymnosarda unicolor* (a school of 12), a very large *Epinephelus lanceolatus*, carangids of different species, acanthurids and *Cheilinus undulatus*. Schools of *Aprion virescens* (often seen as individuals elsewhere) were remarkable. Enije pass held the greatest concentration and size of fish seen in the RMI and the highest number of predatory species, including five species of carangids. Several hawksbill and green turtles were spotted here as well. Surveyors encountered 12 Napoleon wrasses (*Cheilinus undulatus*), five of which were found at the rich Enije channel (Pinca, 2006).

Shark populations on Ailuk were not particularly high; a total of 89 sharks were observed at the 29 survey sites (Pinca, 2006). Sharks were most abundant within and near passes. More than half, 48, were whitetip sharks (*T. obesus*), which were often found sleeping in caves. Although more *C. amblyrhynchos* were spotted in Ailuk than Namu, individuals in the former tended to be young. However, in Ailuk, as in Namu, there were far fewer sharks than at Rongelap in 2003.

*T. obesus* was the most frequently sighted shark species in Ailuk, with at least one record at almost every site. Average abundance for fishes is highest at the northern pinnacles and lowest at the passes. This result is very similar to the distribution of food-fish except that the northwest lagoon site shows the lowest abundance.

*Mangroves of Ailuk Atoll*

Of the five mangrove species that occur in the Marshall Islands, only *Bruguiera gymnorrhiza* reaches the northern Marshalls, which is the limit of mangroves in the Northeast Pacific. Here, mangroves are most often found in depressions inland, as opposed to the normal coastal habitat. The shallow depressions colonized by mangroves are composed hard-bottomed coral limestone in the interior of atoll islets.

A dense mangrove forest of 123 $m^2$ at Bigen, on the windward coast of Ailuk, is growing in a wet limestone depression on the northeast side of the island 65 m inland. The forest is approximately 1.7 m above mean sea level in a saline pond with an alkaline pH of 8.5. All trees were of the species *Bruguiera gymnorrhiza*, and included large mature trees with an average height of 3.3 m interspersed with a dense growth of saplings and young seedlings. How this mangrove area became established inland is unknown. It could either be a relic from mid-Holocene sea-level fall, or introduced by man.

### RMI Foraminifera Populations on Majuro

Recently, thanks to data shared by visiting Japanese researchers, the importance of reef flat foraminifera populations was highlighted. While poor water quality has caused the loss of foraminifera populations along all densely settled shores, robust and luxuriant populations still thrive on the northern shore of Majuro. At low tide, the brown coloration of the reef flat is entirely a consequence of a continuous carpet of living "star sands" (in most cases, *Calcarina*; *Amphistegina* is also locally abundant; Figure 12.22). These organisms can completely cover reef flat macroalgae. The dull, brown coloration of living foraminifera is due to endosymbiotic diatom cells (Figure 12.22). Foraminifera form a strong, thick shell of calcium carbonate 1 mm in diameter, which in aggregate constitutes a major source of lagoon sand.

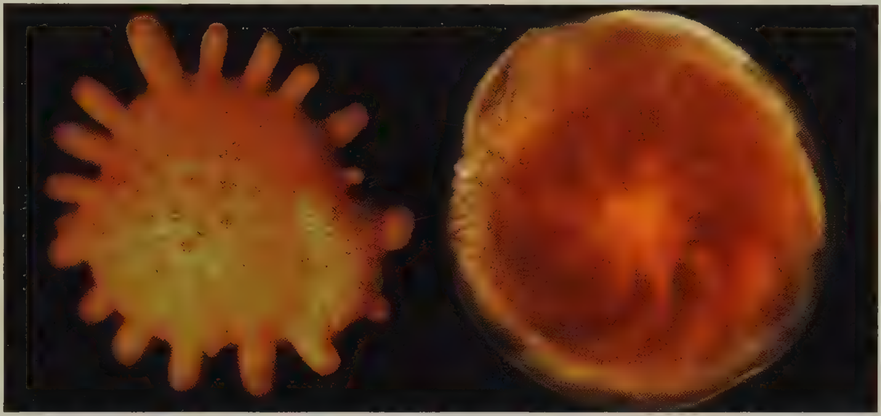


*Figure 12.22. Two species of "living sand" forams.* Calcarina, *with arms (left) and* Amphistegina (right*), both 1 mm in diameter. Photo: D. Jacobson.*

## CURRENT CONSERVATION MANAGEMENT ACTIVITIES

The RMI is a country with very diverse and unique natural resources (Fosberg, 1990), with the balance between terrestrial and marine resources heavily skewed toward the marine (National Biodiversity Team of RMI, 2000). The Marshall Islands have an ancient tradition of sustainable use of marine resources controlled by complex social rules (Weissler, 2001). However, these customary values and practices have been almost entirely lost as a result of 150 years of colonial history, a transition to modern, cash-based lifestyles and the RMI's gradual integration into the global economy. As a consequence, natural resources are being depleted and degraded (Weissler, 2001). Sedimentation, pollution from big oil stocking tankers and foreign fishing vessels, solid waste and sewage disposal, dredging, overexploitation of the marine biological resources for the live fish industry and aquarium trade and extraction for local use (fish, clams and turtles) are some of the most pressing threats to coral reef ecosystems and the coastal environment. Problems of overfishing are becoming increasingly evident, even to fishermen in the outer islands, as in Arno, Likiep and Jaluit. The limited area of land and a rapidly increasing population (1.5% annual rate of increase) are likely to amplify the intensity of anthropogenic threats to reefs, especially waste and sewage disposal.

Fisheries management in the RMI was traditionally accomplished at the direction of local chiefs, but has changed dramatically over the years. One important traditional fisheries management tool implemented by chiefs was the establishment of a "mo". A mo, like a modern marine reserve, was essentially a spatial management tool that instituted taboos against fishing in particular areas in order to conserve food resources and live in harmony with the environment (National Biodiversity Team of RMI, 2000). The rules and regulations for mo varied across the archipelago and would often involve rituals and chants. There was the belief that failure to observe the mo could have significant negative consequences, such as a bad storm for the homeward journey or a tragic accident for a member of the visiting party. Other methods for conserving natural resources included seasonal harvesting of different species and other restrictions. For example, on Wotje Atoll, harvest of coconut crabs included minimum size restrictions, and on Tibon, harvest of females with eggs was prohibited (National Biodiversity Team of RMI, 2000). On some atolls, mo are still known by the community and are respected. In areas where traditional practices have been lost, many local communities have recently begun asking for assistance from national agencies such as the EPA and MIMRA to regulate harvest of resources through reintroduction of mo and other traditional fisheries management practices. Some of the key efforts are mentioned briefly in Table 12.11.

Table 12.11. Conservation efforts in RMI. Source: Re-Imman Project Team, in press.

| NATIONAL EFFORTS ON POLICY, PLANNING AND COORDINATION | |
|---|---|
| 1999-2000 | Development of the National Biodiversity Report and the Biodiversity Strategy and Action Plan |
| 2002 | Establishment of M2EIC* as a collaborative multi-agency group focused on sustainable use of coastal resources, fisheries management and biodiversity conservation |
| 2005 | Drafting of RMI National Coastal Management Framework and Atoll Coastal Management Plans initiated by EPA for Majuro, Jaluit , Wotje and Majuro. |
| 2006 | Evolution of M2EIC to the CMAC and development of a strategic plan |
| **COMMUNITY/ ATOLL-LEVEL DRIVEN EFFORTS** | |
| 1997 | Bikini Atoll declared a protected area under local government ordinance. |
| 1999-2003 | Development of the Jaluit Atoll Plan of Management for conservation and sustainable livelihoods and, in 2003, declaration of Jaluit Atoll Conservation Area as a Ramsar site. |
| 2003 | Ailinginae, Rongelap and Rongerik declared as protected areas under local government ordinances. |
| 2003 | Fisheries management plans for Likiep and Arno Atolls drafted. |
| 2003 | Draft management plan for Mili Conservation Area prepared. |
| 2005 | Fisheries management planning for Majuro initiated. |
| 2007 | Fisheries and conservation management plan for Ailuk Atoll prepared. |

*M2EIC: Acronym for this name compiled from the names of member organizations: MIMRA, MIVA, EPA, CMI and the Ministry of Internal Affairs.

Communities in Ailuki proposed to entirely protect *C. undulatus* from fishing. The scientists fully support this decision and wish it could be the first conservation management maneuver preserving this endangered species to be followed by the entire country. A moratorium on all shark fishing was recommended as well, for which Ailuk could become the first RMI atoll to declare shark fishing illegal in its waters, along with supporting some people's desire to seriously control the harvest of turtles. Although the special importance for the traditional culture is recognized, the continuous harvest of these animals would most certainly deplete them very shortly. The community already proposed to stop collecting turtle eggs and increase laws and awareness on turtle consumption. Other regulations on season and quantity of lobsters catches were included in the management plan.

Researchers and RMI citizens alike have pushed for the establishment of Marine Protected Areas (MPAs) throughout the republic. In a collaborative effort to support MPA planning in the region, RMIEPA, CMI and several other local agencies and tribal organizations are working closely with their counterparts in the Pacific Islands Marine Protected Area Community (PIMPAC). PIMPAC members include regional MPA managers, NGOs, local communities and other stakeholders all working to support the use and management of MPAs in the U.S. Pacific and Freely Associated States. For more information about PIMPAC, visit: http://pimpac.org.

In December 2006, representatives from the RMI attended the Micronesia Challenge Regional Action Planning meeting in Palau. The Micronesia Challenge is a region-wide initiative aimed at conserving at least 30% of nearshore marine resources and 20% of terrestrial resources across Micronesia by 2020. Attendees focused primarily on policy decisions, coordination among members and solidification of conservation goals, among other things. As part of the meeting, each jurisdiction completed a two year work plan that outlines tasks which support the goals of the partnership. In addition to the RMI, members include the Federated States of Micronesia, Guam, Palau and the Commonwealth of the Northern Mariana Islands.

## OVERALL CONCLUSIONS AND RECOMMENDATIONS

Compared to global reef status, coral reefs in the Marshall Islands are still in good condition. It is important to keep this in mind when decisions about both development and resource management are made and implemented. An intact and healthy coral reef is a highly valuable resource that is becoming extremely scarce on a global scale. Wisely managed uses of the marine and terrestrial resources together with ecologically sustainable development will be beneficial, particularly in the face of future challenges (such as increasing populations, climate change and sea level rise).

Under the Micronesia Challenge, the Marshall Islands has agreed to have 30% of nearshore marine resources and 20% of terrestrial resources under "effective conservation". Recently, a national conservation prioritization project, Project Re-Imman, was carried out by multiple national stakeholders: MIMRA, EPA, CMI and various NGOs. The resulting conservation area plan does not attempt to identify specific sites for conservation but rather, develops the principles, process and guidelines for the design, establishment and management of conservation areas that are fully owned, led and endorsed by local communities based on their needs, values and cultural heritage (Re-Imman Project Team, 2008). This plan was developed by a team of resource management professionals from the Marshall Islands and other countries , over an intensive eight month period from November 2006 to July 2007.

Firstly, the project compiled information about biodiversity in the Marshall Islands into a Geographic Information System (GIS). A database was constructed and populated with satellite images of all atolls, atoll maps derived from high resolution satellite imagery, nautical charts and coral reef habitat maps, and information about special biodiversity and cultural features collected from *in situ* research and review of literature and from interviews with local knowledge experts and scientists. This was followed by an intensive series of workshops to develop:

- Objectives for conservation in the Marshall Islands
- Conservation Targets - those elements of biodiversity that we wish to conserve
- Conservation Goals – how much of each Conservation Target is to be conserved and
- Definition of key concepts including "effective conservation", Nearshore Marine Resources, Terrestrial Resources

A working group then developed the *Process for Community-Based Fisheries and Resource Management Planning*, as a set of guidelines for facilitators to assist communities. This project is ongoing and additional accomplishments will be reported in the next edition of this report.

Reef fish and coral diversity can be utilized to prioritize sites that should be protected in a marine reserve network, or other conservation means. In this approach it is important to apply complementarity as a method to identify the best sites. Coral cover, coral complexity and substrate composition are further indicators of reef status and biological integrity. Coral cover is a useful indicator of reef health. The proportion of fleshy seaweed in the substrate composition also indicates the potential conservation value of reefs, since fleshy seaweeds are direct competitors of corals and high levels of algae in combination with decreasing coral cover on suitable substrate may indicate a stressed reef. Furthermore there may be species that have a higher importance in conservation. Such species can be of local commercial or traditional interest, rare or endangered, of charismatic nature, or biological indicators for reef health. Examples are listed in Table 12.12.

*Table 12.12. Examples of indicator species for conservation.*

| CLASS | EXAMPLE |
|---|---|
| Local commercial or traditional interest | Trochus shell, giant clams |
| Rare or endangered | Marine turtles, humphead wrasse |
| Charismatic nature | Whales, dolphins, manta rays |
| Biological indicators for reef health | Butterflyfish |

In selecting a site for a conservation area it is essential to minimize all potential threats to the reefs. If there is a choice of sites, which equally fulfill all other criteria, a site with a lower susceptibility to human or natural threats should preferably be chosen. Different susceptibility can be caused by position, exposure, degree of water flushing, proximity to human settlements and proximity to industrial sites.

Social acceptance is an important factor in the long-term effectiveness of a MPA. It influences compliance, creates stewardship towards the reserve with local people and may interfere less with traditional activities. All sites for marine reserves should be selected in close consultation with local communities affected by the establishment of the reserve. Logistical ease implies that sites with easier access to both visitors and patrolling boats and less exposure might be preferable for establishing a marine reserve. This could minimize effort and human resources required for surveillance and therefore minimize cost.

For the atolls in the RMI, we recommend the establishment of marine reserves as part of a national marine reserve network plan, but also as a community-based coastal resource management effort (Re-Imman Project Team, 2008). Such a reserve network can locally apply the principles of participation, social equity, productivity and self-reliance along with environmental sustainability. At the same time the effort should not be isolated, but be part of a national dialog between local atoll governments or communities and be coordinated by MIMRA.

Any reserve should be part of a coastal resource management plan that details the way the reserve and adjacent resources and areas are managed for the good of all local stakeholders. It should aim to: 1) manage the fishery resources; 2) protect reef ecosystems and all the goods and services they provide; and 3) mange land-based activities to minimize impacts on reefs. We stress the importance on the community-based approach, since when a community becomes responsible of its fishery resources, the people develop a sense of ownership and become protective users.

Important issues to consider in the context of coral reef management and conservation include but are not limited to:

- Fisheries
- Waste disposal
- Tourism
- Traditional use
- Aquaculture and pen holding and
- Energy use

## ATOLL-SPECIFIC RECOMMENDATIONS

### Rongelap Atoll

In Rongelap Atoll, the resource assessment was conducted on reefs all around the atoll, spreading the survey effort relatively evenly. As a result, a map overlaying data for all biological criteria important for marine protected area selection shows "hotspots" where several criteria are fulfilled (Figure 12.23). We recommend a Rongelap reserve network that contains (but is not limited to) sites from several of these hotspots of conservation value around the atoll.

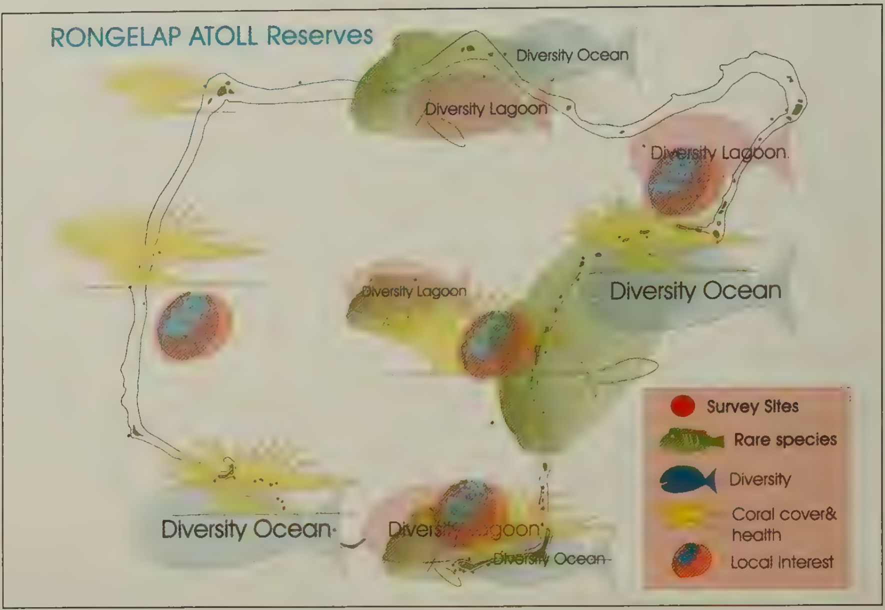


*Figure 12.23. Map of biological integrity at Rongelap Atoll. The overlay shows criteria relevant to reserve selection. Source: Beger and Pinca 2003.*

The reefs around Rongelap Island merit special emphasis in this report. Rongelap Island will harbor the majority of the returning population of Rongelapese people. Thus all human activities such as fishing, waste disposal and boat traffic will be concentrated in this area. However, some of the most diverse, healthy and unique reef formations in the RMI are found here. The site at Jaboan point, Southwest tip of Rongelap Island, is outstanding in reef health and diversity and has already been ear-marked as a protected area by RalGov. The lagoon adjacent to Rongelap Island harbors many small patch reefs and bommies that support an extraordinary variety and abundance of life. Thus, special care should be administered during the resettlement program of Rongelap.

### Namu Atoll:

The sites that, according to the surveys, would be best for conservation have been chosen based on information on total percentage live coral cover, fish abundance, shark sightings and number of giant clams. Sites N19, N17, N20, N18 and N09 (all on the southwestern side of Namu) are the best sites in terms of faunistic richness, based on the above parameters. They are therefore recommended for conservation measures. Moreover, site N06 (Bok passage in the northwest) and N16 (Anil pass in the southwest) should be preserved for their peculiarity, being pass environments (richer due to the current flush and transport of food and larvae) and having special features:

### Majuro Atoll

A number of locations were recommended for conservation sites. Exhibiting high coral cover and diversity, as well as abundant fish stocks and a complex topography, the sites to the east and west of Kolal-en (Calalin) pass were deemed well suited for conservation purposes. The southwest part of the Majuro Atoll (ocean side survey sites) was also highlighted for conservation priority due to high coral cover, fish abundance and the presence of sharks, turtles and Napoleon wrasses. Finally, a monitoring site off Rita Point with its extremely high coral cover, large Acropora tables and megafauna was included as another area well suited for conservation.

### Ailuk Atoll

A striking difference between Ailuk's residents and other atoll communities previously visited by NRAS was in the sense of natural dependency on their oceanic environment. This is probably related to the fact that in Ailuk strong signs of sustainable Marshallese culture can be seen beyond the land itself. For example, while both Namu and Ailuk still harvest and process coconut and pandanus for consumption and trade, the latter is the last example in RMI to heavily depend on outrigger canoes to fish and collect in remote islands of the atoll. This deeper traditional connection with the marine and terrestrial environment naturally increases people's awareness of the strong dependence on a healthy reef for their livelihood, and consequently increases their interest in maintaining it. Moreover, the awareness and education meetings facilitated by the NRAS and Marine Resources Authority representatives helped enormously in increasing and expressing the natural feeling of the local people towards the preservation of resources.

The local community expressed concerns about having "fewer" and "thinner" fish. However this characterization did not seem to be borne out by the surveys. Although there are no baseline data for Ailuk against which to make a comparison, surveys of other atolls suggest that the marine resources of this atoll are quite healthy and deserving the people's continued good stewardship.

The islanders also expressed concern that they had to travel farther to fish. Given the size of the human population, the relatively small size of the atoll and no evidence of harmful fishing practices, any depletion of near-shore fishing populations must simply be the result of over-fishing. It stands to reason that the fish populations closest to the main village would experience the heaviest fishing pressure and hence be the first to suffer population declines.

Following the desire of the local people who have the understanding of the concept of importance and dependency on coral reefs, the obtained results were used to suggest the establishment of permanent no-fishing sites for long-term conservation of the marine resources, crucial to ensuring overall marine resources health, especially under the threats of global climate change and increasing population (Figure 12.24). Specific areas with healthy populations were recommended for conservation. These are the areas with the most biomass aggregation and the feeding grounds to several pelagic species. It was suggested that the passes be extended to the adjacent reef areas near channel entrances, especially where spurs and grooves or giant bommies exist. These sites boast the highest coral and fish diversities observed. Of the four passes surveyed, Enije (To-eje) channel seems to be the best food chain aggregator and the first natural choice for conservation. It appeared to be the richest site visited and analyzed, both in terms of fish and megafauna biomass. This pass was already proposed by the local government of Ailuk as the community proposition for a no-fishing area. In addition, it was suggested to preserve the area comprising the pinnacles, extending into Erappu (To-lap) channel and extending north to include Morok (Toon-malok) channel and adjacencies as well, especially the area around site A20, where a spotted eagle ray, terminal phase *Cheilinus undulatus*, *Eretmochelys imbricata* and a number of *T. obesus* sharks were spotted among coral bommies.

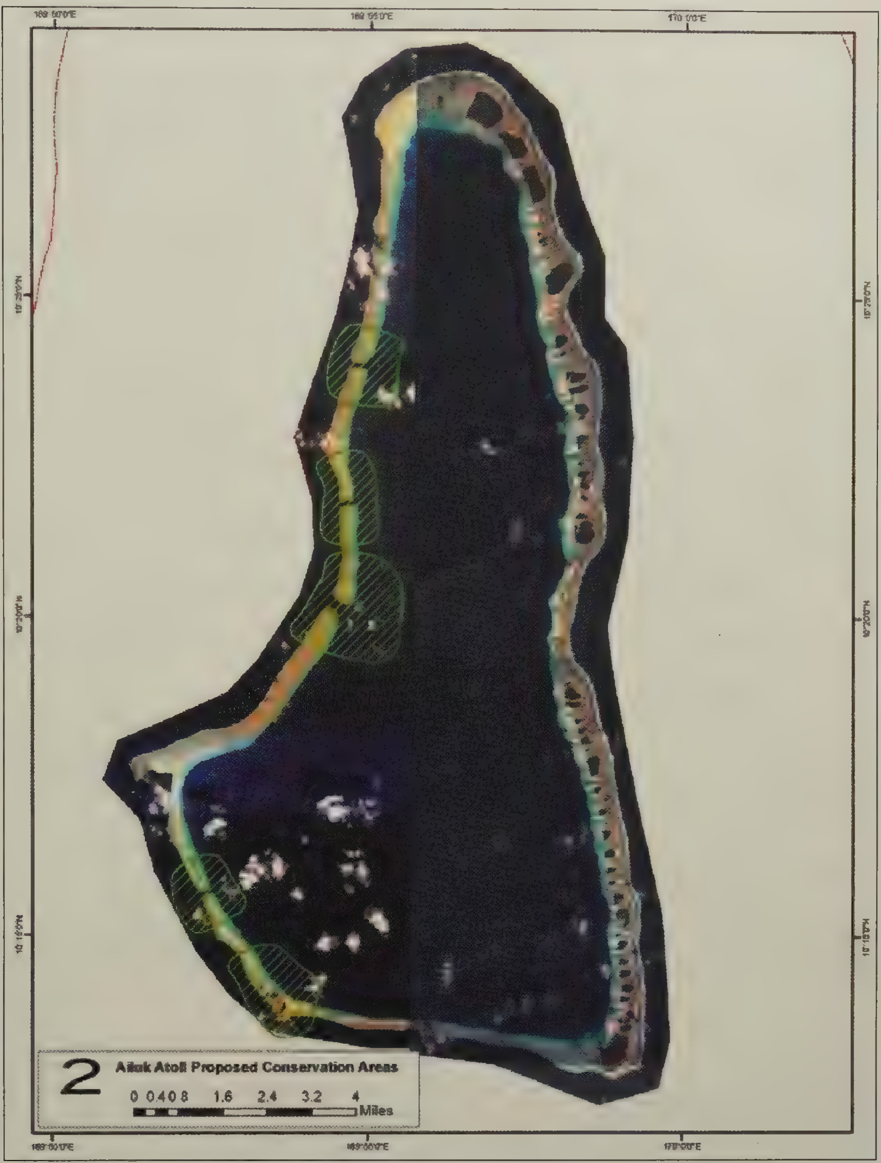


*Figure 12.24. Ailuk atoll and approved conservation sites (areas in green). Source: MIMRA.*

In addition to the passes, a goal of establishing 20% of the atoll in a system of permanent no-take areas representative of all the atoll's marine habitats was recommended. Such percentage of an atoll surface is suggested by many conservation scientists and was mentioned during the community meetings and finally accepted to being included in the Fishery Management Plans, which have been drafted by the Marine Resources Authority and the local fisheries committee with approval by the local council. The community accepted the recommended plan for conservation, but additional education and outreach would help the people understand that intact reef communities are better able to withstand natural fluctuations as well as catastrophic events such as hurricanes, and that these areas are an important source for breeding, repopulation and spill-over.

## REFERENCES

Abraham, T., M. Berger, D. Burdick, E. Cochrane, P. Craig, G. Didonato, D. Fenner, A. Green, Y. Golbuu, J. Gutierrez, M. Hasurmai, C. Hawkins, P. Houk, D. Idip, D. Jacobson, E. Joseph, T. Keju, J. Kuartai, S. Palik, L. Penland, S. Pinca, K. Rikim, J. Starmer, M. Trianni, S. Victor, and L. Whaylen. 2005. Status of the coral reefs in Micronesia and American Samoa. pp 381-409. In: C. Wilkinson (ed.). Status of Coral Reefs of the World: 2004. Global Coral Reef Monitoring Network, Vol 2. Australian Institute of Marine Science, Townsville, Australia. 547 pp.

Armsworth, P.R. 2002. Recruitment limitation, population regulation, and larval connectivity in reef fish metapopulations. Ecology 83: 1092-1104.

Barnett, J. and N. Adger. 2001. Climate dangers and atoll countries. Working Paper 9. Tyndall Centre for Climate Change Research. Norwich, UK. 13 pp.

Beger, M. and S. Pinca. 2003. Coral reef biodiversity community-based assessment and conservation planning in the Marshall Islands: Baseline surveys, capacity building and natural protection and management of coral reefs of the atolls of Rongelap and Mili. Final Report to National Fishery and Wildlife Foundation. Majuro, Republic of the Marshall Islands. 38 pp. http://www.nras-conservation.org/publications.html.

Bellwood, D.R. and T.P. Hughes. 2001. Regional-scale assembly rules and biodiversity of coral reefs. Science 292(5521): 1532-1534.

Bruun, P. 1962. Sea-level rise as a cause of shore erosion. Journal Waterways and Harbours Division 88: 117-130.

Central Intelligence Agency (CIA). 2008. The World Factbook. https://www.cia.gov/library/publications/the-world-factbook/index.html.

Connell, J.H. 1997. Disturbance and recovery of coral assemblages. pp. 9-22. In: H.A. Lessios and I.G. Macintyre (eds.). Proceedings of the 8th International Coral Reef Symposium, Vol. 1. Panama City, Panama. 1040 pp.

Dickinson, W.R. 2006. Temper sands in prehistoric Oceanian pottery: geotectonics, sedimentology, petrography, provenance. Special Paper 406. The Geological Society of America. Boulder, CO. 171 pp.

English, S.A., C.R. Wilkinson, and V.J. Baker (eds.). 1997. Survey manual for tropical marine resources, 2nd edition. Australian Institute of Marine Science. Townsville, Australia. 402 pp.

Forbes, D.L. and S.M. Solomon. 1997. Approaches to vulnerability assessment on Pacific Island coasts: Examples from Southeast Viti Levu (Fiji) and Tarawa (Kiribati). Miscellaneous Report 277. South Pacific Applied Geoscience Commission (SOPAC). Suva, Fiji. 21 pp.

Fosberg, F.R. 1990. A review of the Natural History of the Marshall Islands. Atoll Res. Bull. 330. 99 pp.

Holthus, P., M. Crawford, C. Makroro, and S. Sullivan. 1992. Vulnerability assessment of accelerated sea-level rise-case study: Majuro Atoll, Marshall Islands. South Pacific Regional Environment Programme (SPREP) Reports and Studies Series 60. South Pacific Regional Environment Programme, Apia, Western Samoa. 107 pp.

Ikenoue, H. and K. Adachi. 2004. Majuro Atoll fisheries state research for community based fisheries management: Project for inshore fisheries resource study and management in atoll areas (atoll project). Marshall Islands Marine Resources Authority and Overseas Fisheries Cooperation Foundation. Majuro, Republic of the Marshall Islands.

Intergovernmental Panel On Climate Change (IPCC). 2007. Climate change 2007: Mitigation of Climate Change. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. B. Metz, O.R. Davidson, P.R. Bosch, R. Dave, and L.A. Meyer (eds.). Cambridge University Press, Cambridge, UK and New York, NY. 851 pp. http://www.mnp.nl/ipcc/pages_media/AR4-chapters.html.

Jackson, J. B., C. Jackson, M.X. Kirby, W.H. Berger, K.A. Bjorndal, L.W. Botsford, B.J. Bourque, R.H. Bradbury, R. Cooke, J. Erlandson, J.A. Estes, T.P. Hughes, S. Kidwell, C.B. Lange, H.S. Lenihan, J.M. Pandolfi, C.H. Peterson, R.S. Steneck, M.J. Tegner, and R.R. Warner. 2001. Recent Collapse of Coastal Ecosystems. Science 293(5530): 629-637.

Jacobson, D.M. In preparation. Fine scale temporal and spatial dynamics of a Marshall Islands coral disease outbreak.

Kospartov, M., M. Beger, D.M. Ceccarelli, and Z.T. Richards. 2006. An assessment of the distribution and abundance of fish, coral, sea cucumbers, trochus, giant clam and invasive marine species at Ashmore Reef and Cartier Reef Commonwealth Marine Reserves: 2005. Report for the Department of Heritage and Environment, Australian Government. UniQuest, Queensland, Australia. 300 pp.

Madin, J.S. and S.R. Connolly. 2006. Ecological consequences of major hydrodynamic disturbances on coral reefs. Nature 444: 477-480.

McClanahan, T.R. and S. Mangi. 2001. The effect of a closed area and beach seine exclusion on coral reef fish catches. Fish. Manage. Ecol. 8(2): 107–121.

McKenzie, E., A. Woodruff, and C. McClennen. 2006. Economic assessment of the true costs of aggregate mining in Majuro Atoll, Republic of the Marshall Islands. South Pacific Applied Geoscience Commission (SOPAC). Suva, Fiji. 71 pp.

Niedenthal, J. 2001. For the good of mankind: a history of the people of Bikini and their islands. Bravo Publishers. Majuro, Republic of the Marshall Islands. 226 pp.

Noshkin, V.E., R.J. Eagle, and W.L. Robison. 1997a. Fine and coarse components in surface sediments from Bikini lagoon. Report UCRL-ID-126358. Lawrence Livermore National Laboratory and U.S. Department of Energy. Livermore, CA. 27 pp.

Noshkin, V.E., W.L. Robison, K.M. Wong, J.L. Brunk, R.J. Eagle, and H.E. Jones. 1997b. Past and present levels of some radionuclides in fish from Bikini and Enewetak atolls. Health Phys. 73: 49-65.

Peterson, E.L., M. Beger, and Z.T. Richards. 2005. Hydrodynamics and biodiversity used to propose MPAs at Rongelap Atoll. pp. 27-31. In: J.C. Day, J. Senior, S. Monk, and W. Neal (eds.). Proceedings of the 1st International Marine Protected Areas Congress conference (IMPAC 1). Geelong, Australia. 665 pp.

Peterson, E.L., M. Beger, and S. Pinca. 2006. Three dimensional model of atoll hydrodynamics. pp. 1434-1439. In: Y. Suzuki, T. Nakamori, M. Hidaka, H. Kayanne, B.E. Casareto, K. Nadaoka, H. Yamano, and M. Tsuchiya (eds.). Proceedings of the 10th International Coral Reef Symposium. Okinawa, Japan. 1950 pp.

Pinca, S. 2001. Marine Resource and Biodiversity Identification and Survey: Likiep Atoll 2001, Final Report. Marshall Islands Marine Resources Authority. Republic of the Marshall Islands. 159 pp.

Pinca, S. 2003. Marshall Islands surveys to support a national effort towards reef conservation. Secretariat of the Pacific Community (SPC) Women in Fisheries Information Bulletin 13: 31-33. http://www.nras-conservation.org/nraslibrary/PincaSPC_2003.pdf.

Pinca, S. 2005. Majuro Marine Resources Assessment, 2004. National Resource Assessments Surveys (NRAS) – Conservation. Majuro, Republic of the Marshall Islands.

Pinca, S. 2006. Ailuk Marine Resources Assessments, 2006. National Resource Assessments Surveys (NRAS) – Conservation. Majuro, Republic of the Marshall Islands. 10 pp. http://www.nras-conservation.org/publications.html.

Pinca, S., M. Beger, and A. Hengeveld (eds.). 2004a. Mili Atoll Marine Surveys, 2003. National Resource Assessments Surveys (NRAS) - Conservation. Majuro, Republic of the Marshall Islands. http://www.nras-conservation.org/publications.html.

Pinca, S., M. Beger, and A. Hengeveld (eds.). 2004b. Rongelap Atoll Marine Surveys, 2003. National Resource Assessments Surveys (NRAS) - Conservation. Majuro, Republic of the Marshall Islands. 11 pp. http://www.nras-conservation.org/publications.html.

Pinca, S., M. Beger, D. Jacobson, and T. Keju. 2005. The State of Coral Reef Ecosystems of the Marshall Islands. pp. 373-386. In: J.E. Waddell (ed.). The State of Coral Reef Ecosystems of the United States and Pacific Freely Associated States: 2005. NOAA Technical Memorandum NOS NCCOS 11. Silver Spring, MD. 522 pp.

Rahmstorf, S. 2007. A semi-empirical approach to projecting future sea-level rise. Science 315 (5810): 367-370.

Re-Imman National Planning Team. 2008. Reimaanlok: National Conservation Area Plan for the Marshall Islands 2007-2012. Published by: N. Baker. 82 pp.

Richards, Z.T. and C.C. Wallace. 2004. *Acropora rongelapensis* sp. nov, a new species of *Acropora* from the Marshall Islands (Scleractinia: Astrocoeniina: Acroporidae). Zootaxa 590: 1-5.

Richards, Z.T., M. Beger, S. Pinca, and C.C. Wallace. In press. Bikini Atoll coral biodiversity resilience revealed; five decades after nuclear testing. Mar. Poll. Bull.

Roberts, C.M., J.A. Bohnsack, F.R. Gell, J.P. Hawkins and R. Goodridge. 2001. Effects of marine reserves on adjacent fisheries. Science 294(5548): 1920-1923.

National Biodiversity Team of RMI. 2000. The Marshall Islands-Living Atolls Amidst the living Sea. St. Hildegard Publishing Company. Santa Clarita, CA. 345 pp.

Sladek Nowlis, J.S. and C.M. Roberts. 1999 Fisheries benefits and optimal design of marine reserves. Fish. Bull. 97: 604-616.

Smith, R. and J. Collen. 2004. Sand and gravel resources of Majuro Atoll, Marshall Islands. SOPAC Technical Report 360. South Pacific Applied Geoscience Commission. Suva, Fiji. 126 pp. http://www.sopac.org/data/virlib/TR/TR0360.pdf.

Vander Velde, N. and B. Vander Velde. 2006. Mary's bean and other small drift materials of plant origin found on Bikini Atoll. Plant Species Biol. 21: 41-48.

Weissler, M.I. 2001. Precarious landscapes: prehistoric settlement in the Marshall Islands. Antiquity 75: 31-32.

Willis, B. James Cook University. Townsville, Australia. Personal communication.

Yamaguchi, T., M. Chikamori, H. Kayanne, H. Yamano, H. Yokoki, and Y. Najima. 2006. Conditions and activities supporting early prehistoric human settlement on Majuro Atoll in Marshall Islands, Eastern Micronesia. pp. 1549-1555. In: Y. Suzuki, T. Nakamori, M. Hidaka, H. Kayanne, B.E. Casareto, K. Nadaoka, H. Yamano, and M. Tsuchiya (eds.). Proceedings of the 10th International Coral Reef Symposium. Okinawa, Japan. 1950 pp.

# The State of Coral Reef Ecosystems of the Federated States of Micronesia

Andy George[1], Marston Luckymis[1], Steve Palik[2], Katrina Adams[3], Eugene Joseph[4], Dave Mathias[5], Scotty Malakai[5], Mary Rose Nakayama[6], Curtis Graham[6], Kerat Rikim[7], Allan Marcus[7], Julita Albert[8], Vanessa Fread[9], Mike Hasurmai[10], Christina Fillmed[11], Willy Kostka[12], Alissa Takesy[13], Trina Leberer[14] and Shauna Slingsby[15]

## INTRODUCTION AND SETTING

The Federated States of Micronesia (FSM) is comprised of 607 islands found within four states. From east to west, Kosrae, Pohnpei, Chuuk and Yap span 1.6 million km$^2$ of the western Pacific Ocean from 1.0–9.90 N longitude and 138.2–162.60 E latitude (Figure 13.1). Each island or group has its own language, customs, local government and traditional system for managing marine resources. The FSM has a total landmass of 702 km$^2$ comprised of both high islands and atolls, with land elevation ranging from sea level to about 760 m (2,500 ft; FSM National Biodiversity Strategic Action Plan, 2003). Trade winds prevail from December through April, with periods of weaker winds and doldrums occurring from May to November. Rainfall is extremely high on the high volcanic islands of Kosrae, Pohnpei and Chuuk, and can exceed 10 m (400 in) a year (South Pacific Regional Environment Programme, 1993; Lindsay and Edward, 2000). The islands support three basic reef formations: fringing reefs, barrier reefs and atolls (U.S. Army Corps of Engineers, 1985; USACE, 1986; USACE, 1987; USACE, 1988; USACE, 1989a; USACE, 1989b). Islanders have a strong dependence on coral reefs and marine resources, both economically and culturally (Falanruw, 2004; FSM, 2004; FSM, 2003; The Nature Conservancy, 2003).

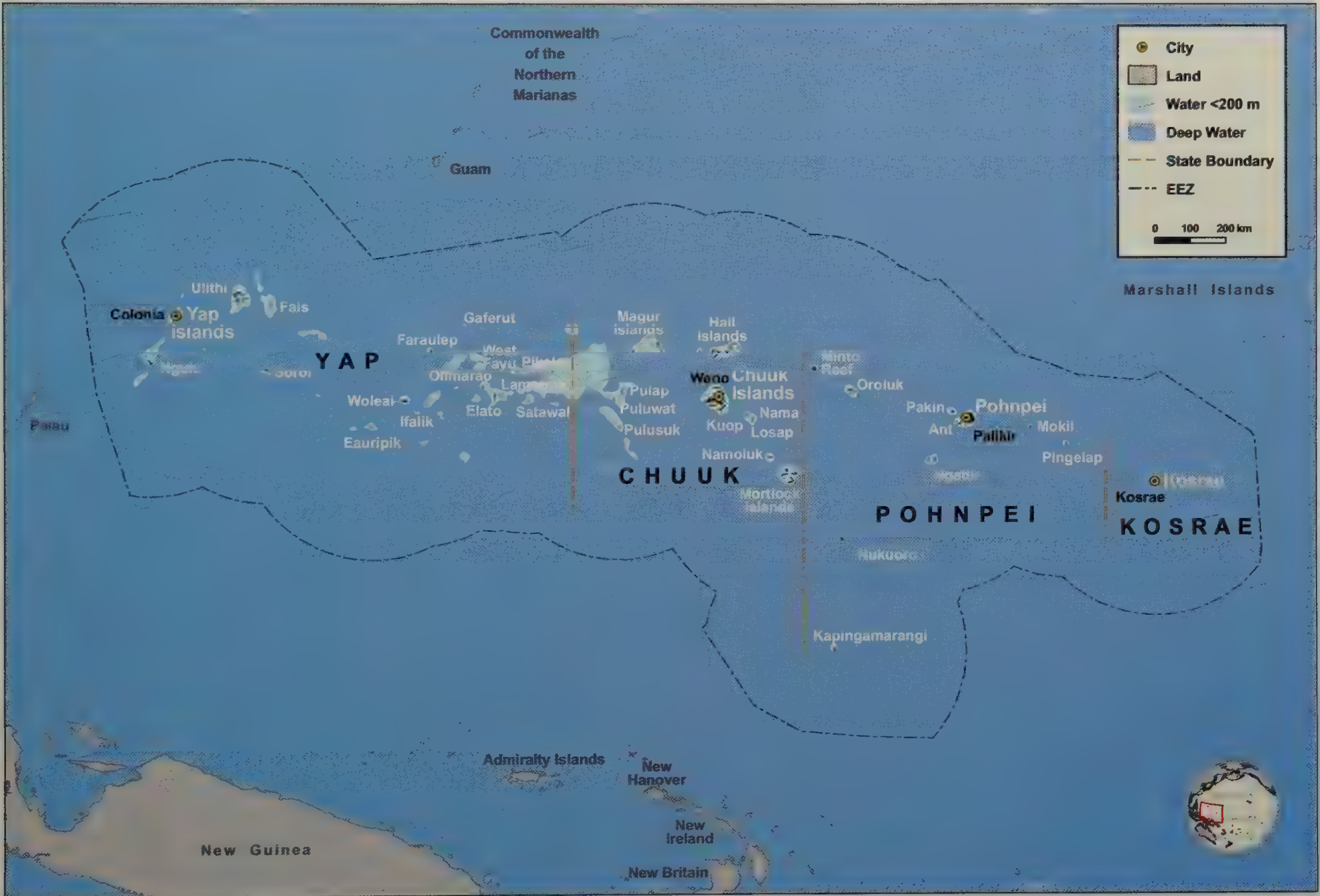

Commonwealth of the Northern Marianas
Guam
City
Land
Water <200 m
Deep Water
State Boundary
EEZ
0 100 200 km
Marshall Islands
Ulithi
Fais
Colonia
Yap Islands
Sorol
YAP
Gaferut
Faraulep
West Fayu
Olimarao
Woleai
Ifalik
Eauripik
Elato
Satawal
Magur Islands
Hall Islands
Pulap
Puluwat
Pulusuk
Weno
Chuuk Islands
Nama
Kuop
Losap
Namoluk
CHUUK
Mortlock Islands
Minto Reef
Oroluk
Pakin
Pohnpei
Ant
Palikir
Mokil
Pingelap
POHNPEI
Nukuoro
Kapingamarangi
Kosrae
KOSRAE
Palau
Admiralty Islands
New Hanover
New Ireland
New Britain
New Guinea

*Figure 13.1. Locator map of FSM showing state boundaries and the FSM Exclusive Economic Zone. Map: K. Buja.*

---

1. Kosrae Conservation and Safety Organization
2. Conservation Society of Pohnpei
2. Kosrae Marine Surveillance Division
3. Kosrae Reef Protection Community Action Committee Partner
4. Conservation Society of Pohnpei
5. Pohnpei Marine Conservation Unit
6. Chuuk Conservation Society
7. Chuuk Department of Marine Resources
8. Chuuk Environment Protection Agency
9. Yap Community Action Program
10. Yap Marine Resource Management Division
11. Yap Environment Protection Agency
12. Micronesia Conservation Trus
13. FSM Department of Resources and Development
14. The Nature Conservancy Micronesia Program
15. NOAA Coral Reef Conservation Program

The state of Kosrae is a single volcanic island with a land mass of 109 km$^2$ and a maximum elevation of 629 m. Kosrae is surrounded by a fringing reef and has three harbors. In areas where the reef flat is wide, there are a number of large solution holes, some of which support extensive coral development (USACE, 1987). The reef is narrow along the east and south coasts, but nearly wide enough along the west and north coasts to be considered a barrier reef. The island is surrounded by coastal mangrove forest and extensive fringing reefs. Kosrae's reefs and mangroves are considered some of the healthiest in Micronesia (Donaldson et al., 2007) and support a small but growing SCUBA diving and ecotourism industry. However, recent coastal development and land use patterns have resulted in some coastal erosion and degradation of the coastal mangrove ecosystem, placing the health of Kosrae's reefs at risk (Maragos, 1993).

The volcanic island of Pohnpei, the site of the FSM capital, is the largest island in the FSM (345 km$^2$) and along with eight smaller islands and atolls, makes up the state of Pohnpei. Pohnpei Island has a well-developed barrier reef and associated lagoon (Figure 13.2). Pohnpei has outstanding biological significance. It is one of the few central Pacific high island "bridges" that enabled marine and terrestrial life to migrate from the Indo-Malay region into the Pacific. This characteristic, along with its geographic isolation, has resulted in high levels of species diversity and endemism (FSM NBSAP, 2003). Pohnpei's extensive reefs and lagoon feature a wide diversity of productive and relatively intact natural habitats, including barrier reefs, fringing reef flats, reef passages, seagrass beds and mangroves. These habitats support a remarkable abundance of marine life, including more than 650 species of fish and nearly 350 species of coral (Allen, 2005; Turak and DeVantier, 2005). Pohnpei boasts the world's lowest dwarf cloud forest at 450 m elevation. Pohnpei's Nanmeir en Salapwuk Valley holds what is considered to be the largest intact lowland tropical forest in the Pacific outside of Hawaii. The people of Pohnpei, like those in many developing Pacific nations, depend on marine resources for subsistence and cash income.

*Figure 13.2. Pohnpei, the largest island in the FSM, is the country's political and administrative capital; Pohnpei's well-developed barrier reef and expansive lagoon encompass marine habitats that support abundant marine life. Photo: J. Waddell.*

The state of Chuuk is made up of five island regions: Chuuk Lagoon, Mortlocks, Pattiw, Halls and Nomunweito. The state makes up half of the total FSM population (Figure 13.3), and the Chuukese people are highly dependent on the marine environment for subsistence. Although Chuuk has extensive coral reef resources (TNC, 2003), it has very limited economic resources. Chuuk Lagoon is the largest atoll in the FSM and serves as the population and political center of Chuuk State.

Yap State contains four main islands known as Yap Proper or Wa'ab, with a land area of approximately 100 km$^2$, and an additional 15 islands and atolls. The lifestyle of Yap islanders is among the most traditional in the FSM, with a highly sophisticated marine tenure and marine resource management system (Smith, 1994). The Yap outer islands consist of three raised coralline islands and 12 coral atolls. Two of the raised islands (Fais and Satawal) and nine of the atolls (Ngulu, Ulithi, Sorol, Eauripik, Woleai, Ifaluk, Faraulep, Elato and Lamotrek) are inhabited. The fringing reef surrounding Wa'ab is broad and mostly shallow (<3 m) but in some places reaches depths >10 m (Orcutt et al., 1989).

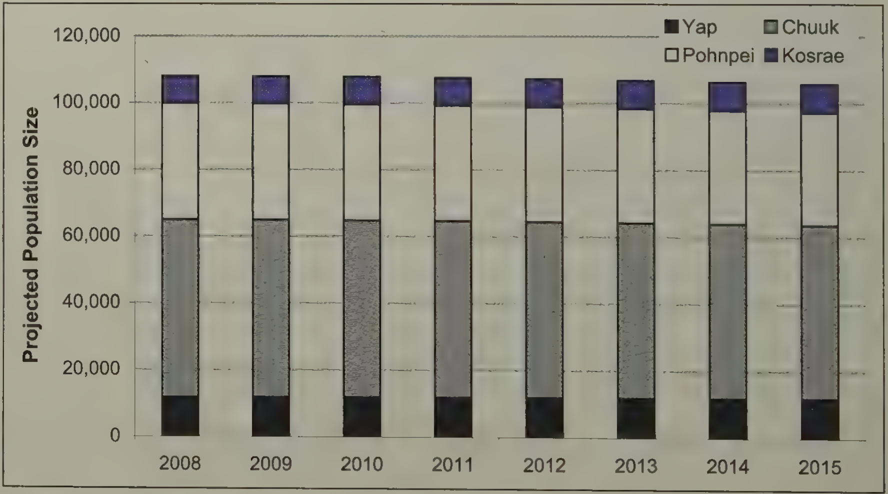


*Figure 13.3. Projected population size, by state, from 2008-2015. Chuuk is projected to continue to make up half of the FSM population. Source: FSM Division of Statistics, http://www.spc.int/prism/country/FM/stats/.*

## ENVIRONMENTAL AND ANTHROPOGENIC STRESSORS

### Climate Change and Coral Bleaching

Only one major coral bleaching event has been recorded in Kosrae in the past. In 2004, *Acropora* species in front of the Kosrae Phoenix Resort on the northeast coast were observed to be bleached. Other than this localized event, there has been very little coral bleaching reported in Kosrae. Instances of coral bleaching in Kosrae are believed to have been caused by increases in sea water temperatures. A minor and localized coral bleaching event involving *Acropora* species was observed at the northeastern barrier reef of Pohnpei in 2004, but the corals were fully recovered by 2005. Since then there have been no reports of coral bleaching in Pohnpei. According to preliminary results from the Yap rapid ecological assessment (REA) that took place July 11–August 2, 2007, some coral bleaching was seen on the reef flats of Ngulu and Ulithi Atolls, and there is evidence of a possible bleaching event resulting in some mortality at Ngulu Atoll that may have occurred more than 10 years ago (E. Turak, pers. comm.).

### Diseases

The number of incidences of disease in the corals of Kosrae is quite small and within normal range. Although coral disease is also quite rare in Pohnpei, monitoring for diseases still needs to be incorporated into the coral monitoring plan.

### Tropical Storms

Tropical storms frequently pass through or near the FSM. Although there have not been any destructive storms in the past three years, in early 2004 Typhoon Sudal passed by Chuuk and directly hit Yap , causing structural damage to reefs (Figure 13.4). The recent effects of tropical storms on corals in Kosrae appear to be minimal, and no data are available for Pohnpei, Chuuk or Yap.

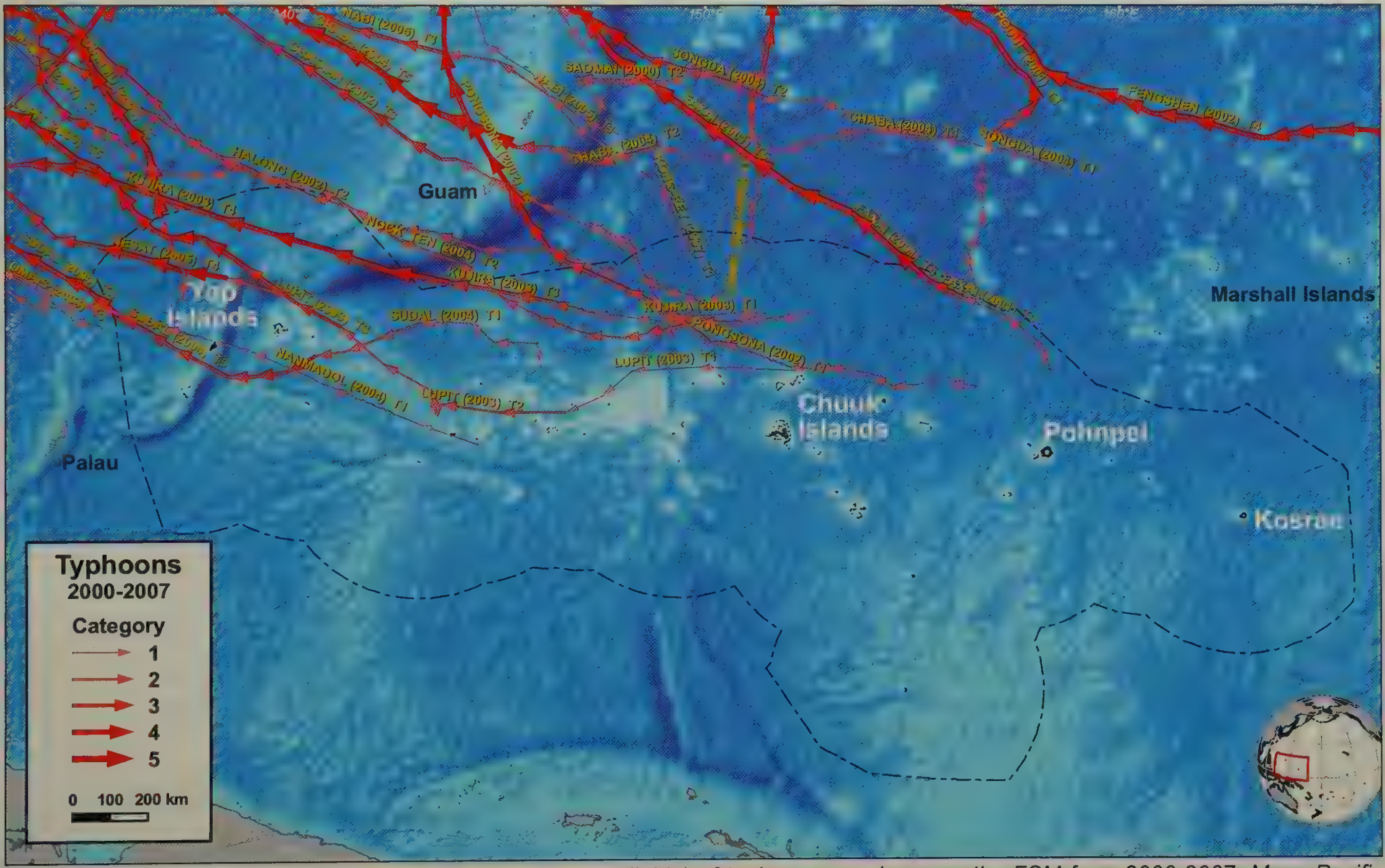

140°
150°
160°E
NABI (2005) T3
SAOMAI (2000) T2
SONGDA (2004) T2
NABI (2005) T3
PONGSONA (2002)
CHABA (2004) T2
CHABA (2004) T1
SONGDA (2004) T1
FENGSHEN (2002) T4
HALONG (2002) T2
KUJIRA (2003) T4
NOCK-TEN (2004) T2
KUJIRA (2003) T3
KUJIRA (2003) T1
PONGSONA (2002) T1
SUDAL (2004) T1
LUPIT (2003) T1
LUPIT (2003) T2
LUPIT (2003) T3
NANMADOL (2004) T1
Guam
Yap Islands
Palau
Chuuk Islands
Pohnpei
Kosrae
Marshall Islands
Typhoons
2000-2007
Category
1
2
3
4
5
0 100 200 km

*Figure 13.4. The path, intensity, year and name (when available) of typhoons passing near the FSM from 2000-2007. Many Pacific typhoons are not named or the names are not recorded in the typhoon database. Map: K. Buja. Source: http://weather.unisys.com/hurricane/.*

### Coastal Development and Runoff

Over the past 20 years the availability of large amounts of funding for infrastructure improvements under the Compact of Free Association with the U.S. has led to increased dredging, road construction and land clearing. For example, in fiscal year 2007, $6.1 million was allocated to the Infrastructure Sector (http://www.doi.gov/oia/Firstpginfo/compactgrants/index.html). Sedimentation from these land-based activities, as well as agriculture, has contributed to the degradation of nearshore coral reef ecosystems in all four states (TNC, 2003). Coastal development is the lead cause of soil erosion and sedimentation in Kosrae. The construction of the circumferential road to connect Utwe and Walung exacerbates the impacts of soil erosion and sedimentation on the corals along Kosrae's southern reefs. Housing developments for residential and business purposes along the coast also contribute a great deal to the problem of sedimentation. Coastal development is one of the biggest stressors to the coral reefs of Pohnpei as well, with more than 50 dredge sites and mangrove clearings (man-made channels) surrounding the coast. According to Yap Environmental Protection Agency (YEPA), large volumes of dredged coralline materials (50,000-150,000 $yd^3$/ project) are regularly used for construction projects (Figure 13.5).

### Coastal Pollution

Construction of pigpens and placement of sewage outfalls near coastal areas and rivers in Kosrae affect the health of corals. Landfills within mangrove areas and the conversion of mangroves into dump sites are major contributors to coastal pollution as well. In Pohnpei, coastal pollution is localized mostly at river mouths and estuaries. Poor land use practices and inadequate waste management are resulting in the accumulation of solid wastes on shorelines that eventually make their way into the lagoon.

### Tourism and Recreation

Overall, the number of tourists visiting the FSM has remained relatively steady since 2002 (Figure 13.6). Kosrae receives relatively few tourists each year. The few that visit Kosrae come primarily to enjoy diving and snorkeling as well as canoe rides within the mangrove channels of Utwe and Walung. These tourists are amongst the most environmentally conscious in the world. As a result, the impacts from the tourism industry on the corals in Kosrae are minimal.

### Fishing

Overfishing has been identified as the most urgent and critical threat across biologically significant marine areas in all states (TNC, 2003). Both population growth and a shift from subsistence to commercial harvest over the past 30 years have put pressure on FSM's coral reefs (Figure 13.7) despite an overall decline in the number of people employed in the fishing industry (Figure 13.8). The breakdown of traditional management systems throughout Micronesia has also contributed to overharvesting (Smith, 1994). In Kosrae, destructive fishing methods that are commonly used by fishermen impact fish populations much more than the corals. Poisonous roots and bleaches are used on the reef flats and within the lagoon to kill

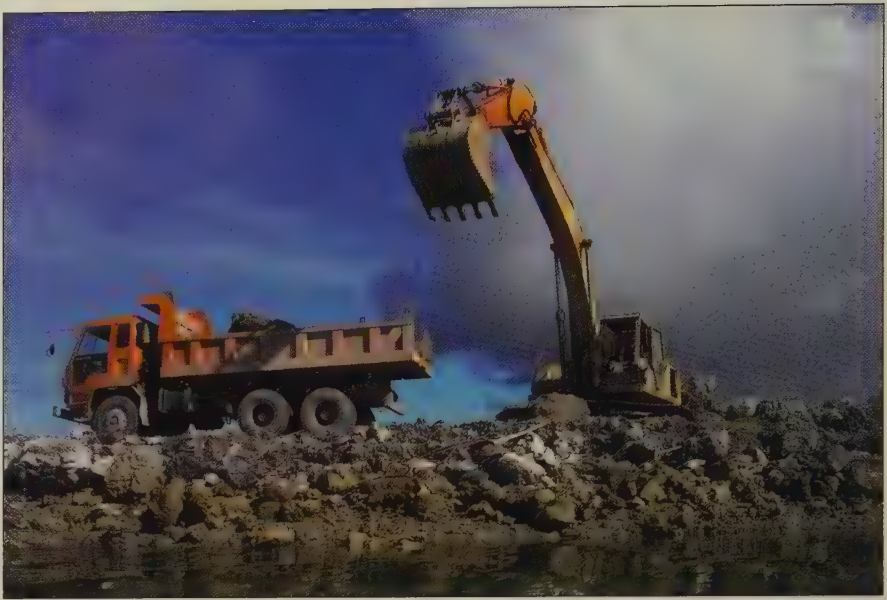


Figure 13.5. Dulkan dredge site in Yap. Photo: L. Johnson.

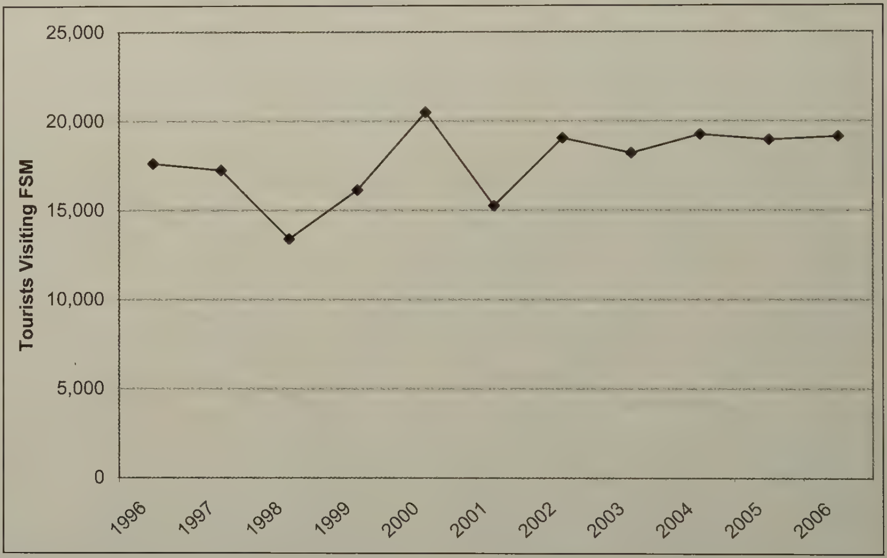


Figure 13.6. The number of international tourists visiting the FSM from 1996-2006. Source: FSM Division of Statistics, http://www.spc.int/prism/country/FM/stats/.

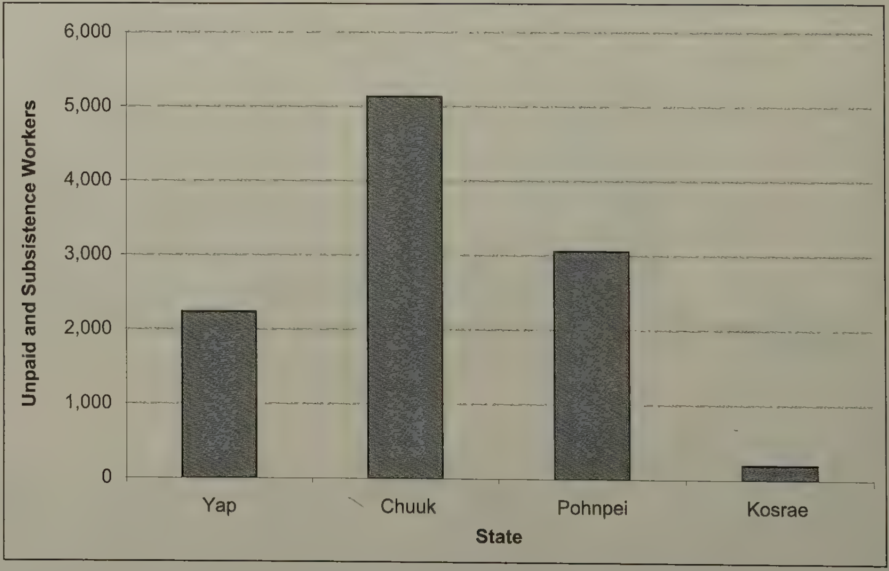


Figure 13.7. The number of unpaid or subsistence workers across the FSM. Source: FSM Division of Statistics, http://www.spc.int/prism/country/FM/stats/; 2000 FSM Census.

large numbers of fish. Dynamite fishing is not commonly used, but net fishing is common in Kosrae (Figure 13.9).

In Pohnpei, a market-based analysis was conducted in 2006 by the Conservation Society of Pohnpei (CSP) in conjunction with ongoing ecosystem assessment efforts in order to determine the condition of Pohnpei's reef fisheries. Both concluded that the reef fish populations in Pohnpei are being overfished and that present harvest levels are unsustainable. Without an overarching policy that combines habitat protection and fishery management practices, Pohnpei's fishery resources are likely to continue to decline dramatically. The market-based analysis indicated that at a minimum, 2,500 lbs of reef fish are being sold daily at local markets (approximately 1,000,000 lbs per year). These estimates do not include subsistence catch, fish sold to schools and hospitals, or exports. If estimates of these catches are taken into account, it is likely that the amount of fish taken from Pohnpei's reefs exceeds 4,000 lbs daily (approximately 1,500,000 lbs annually). Lack of a current policy to regulate size limits and sales, and an undervalued market price are all significant factors contributing to the overfishing problem. Market-based analysis indicated that at least 70% of all the fish sold at markets are immature fish. Removal of adult female fish with eggs further reduces opportunities for replenishment of reef fish populations. Also, the study indicated that spear fishing at night, which is the most popular type of fishing, gives an unfair advantage to the fishermen and contributes to the overall decline in reef fisheries. Pohnpei fishermen predominantly target four families of reef fish: unicorn fish, grouper, parrotfish and jacks. When seasonal bans are in effect for groupers (March and April), more parrotfish are recorded in the markets.

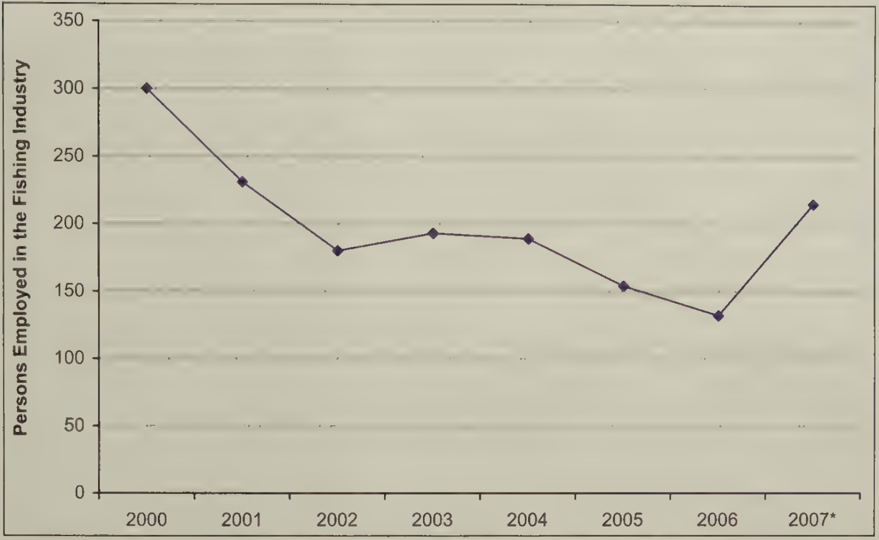


*Figure 13.8. The number of persons employed by the fising industry in the FSM between 2000 and 2006. An asterisk (*) indicates a projected value. Source: FSM Division of Statistics, http://www.spc.int/prism/country/FM/stats/Economic/LMrkt/LMrkt_FY07est.pdf.*

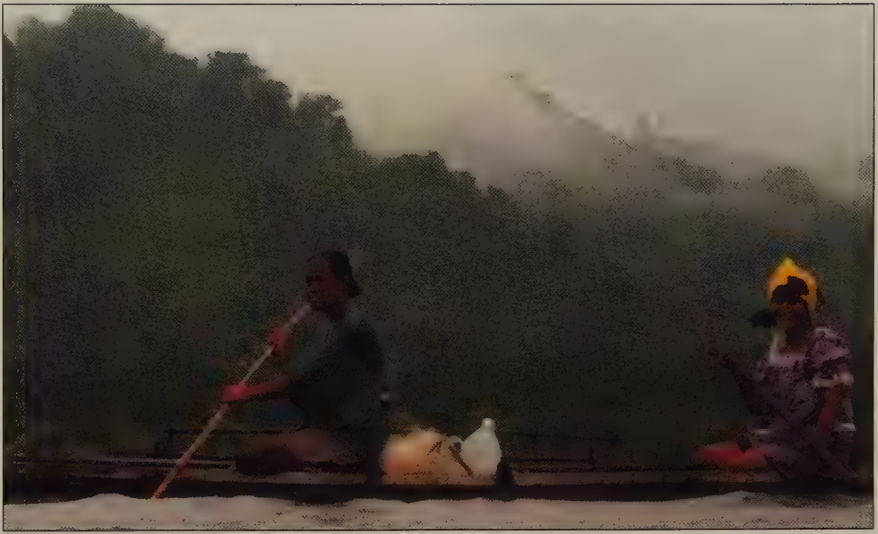


*Figure 13.9. Women net-fishing in Kosrae. Photo: K. Adams.*

## Trade in Live Coral and Live Reef Species

As of 2006, there was still no local market for trade in live coral and reef species in Kosrae. However, in 2006 a foreign investment permit was issued for live coral exportation for the aquarium trade. The project has not begun yet as it awaits a development permit from the Kosrae Island Resource Management Authority.

According to preliminary results from the Yap REA sites, broken and dead coral were observed at Ngulu Atoll. The damage was believed to be associated with illegal cyanide fishing for large Napoleon wrasse (*Cheilinus undulatus*) captured stunned but alive by foreign fishing vessels (E. Turak, pers. comm.).

## Ships, Boats and Groundings

In the past three years, there were no incidents of ship or boat groundings in Kosrae. However, some boats have grounded on reefs in the other states, such as at Elato Atoll in Yap (Figure 13.10). According to preliminary results from the Yap REA, a large swath of physical damage on a patch reef in Ngulu Atoll may have been the result of a ship grounding that occurred within the past several years (E.Turak, pers. comm.). However, recovery of the area was expected, as many coral recruits approximately 3-5 years old were observed (E. Turak, pers. comm.).

## Marine Debris

Locally generated marine debris is another threat that is affecting Kosrae's marine ecosystem. However, environmental awareness campaigns to remove debris have been carried out by conservation agencies and organizations on the island.

## Aquatic Invasive Species

In 2005, the Bishop Museum sponsored a workshop in the FSM focused on aquatic invasive species. The workshop provided an overview of the impacts of certain aquatic species in the region and eradication measures that have been taken to date (L. Eldridge, pers. comm.). Currently the impacts of aquatic invasive species in the FSM are unknown. However, preliminary findings from the Kosrae REA identified an invasive corallimorph (*Rhodactis howsii)* at one of the sites surveyed in 2006 (Donaldson et al., 2007).

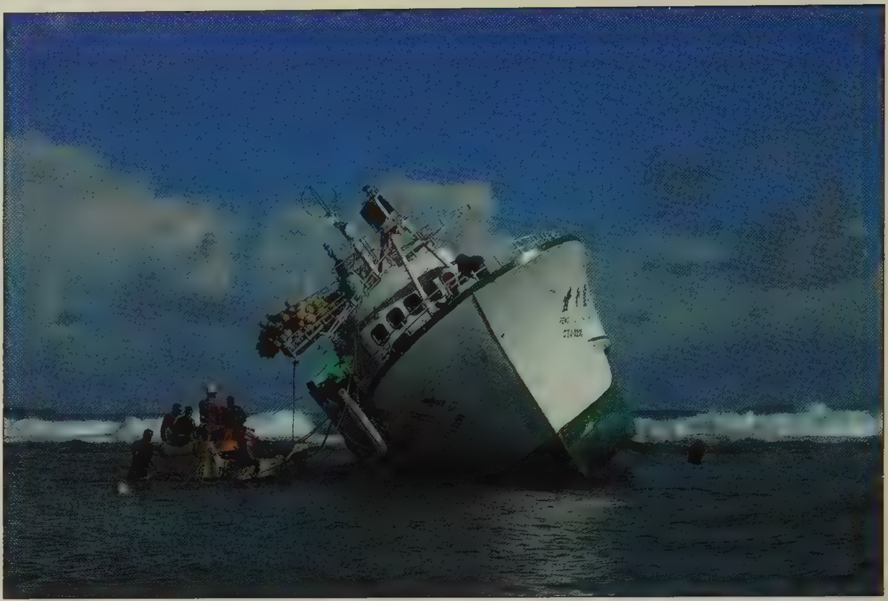


*Figure 13.10. Removing oil from a grounded vessel on Elato Atoll in Yap. Photo: L. Johnson.*

## Security Training Activities

No security training activities currently occur in the FSM.

## Offshore Oil and Gas Exploration

No offshore oil and gas exploration currently occurs in the FSM.

## Other

### *Crown-of-thorns Sea Star (Acanthaster planci)*

An infestation of *crown-of-thorns sea stars* (*COTS*) in 1994 resulted in coral mortality along the western side of Kosrae. An eradication project was implemented and carried out by the Marine Resources Division and dive operators on the island. During coral monitoring surveys in Pohnpei, COTS were found to be widely distributed and present in densities approaching outbreak levels (Figure 13.11). Continuing predation by COTS appears to be altering the structure of coral communities (Turak and DeVantier, 2005).

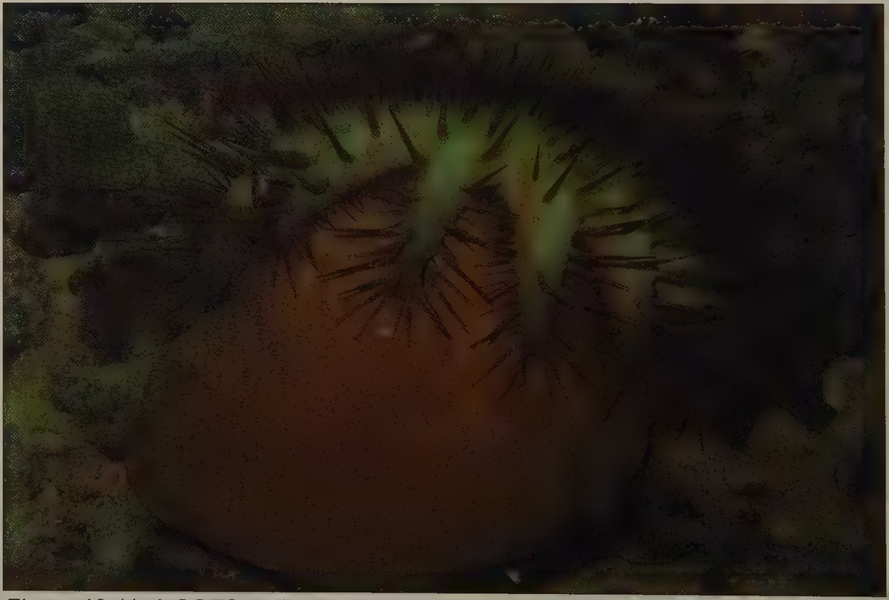


*Figure 13.11. A COTS eating* Porites *in Pohnpei. Photo: E. Turak.*

## CORAL REEF ECOSYSTEMS—DATA-GATHERING ACTIVITIES AND RESOURCE CONDITION

Each state in the FSM has two government regulatory agencies that manage coral reef ecosystems: Marine Resources Divisions (MRD) and Environmental Protection Agencies (EPA). The local non-governmental organizations (NGOs) focused on coral reef conservation in each state, including Yap Community Action Program (YapCAP), Chuuk Conservation Society (CCS), Conservation Society of Pohnpei (CSP) and Kosrae Conservation and Safety Organization (KCSO), also work with government agencies and local communities to protect and monitor coral reef resources. Regional organizations such as the Secretariat of the Pacific Region Environmental Programme (SPREP) and The Nature Conservancy (TNC) offer technical and financial assistance for reef-related programs. Additionally, U.S. Peace Corps volunteers in the FSM assist local counterparts in government agencies, NGOs and local communities as part of the Natural Resource Conservation and Development program.

The four states of the FSM are at different stages of development and implementation of coral reef monitoring programs. Some individual monitoring efforts have been in effect since 1994 (Table 13.1), but recently the FSM has started to develop and implement a more standardized monitoring program across the country. Because coral ecosystem monitoring is at such an early stage in FSM, all monitoring results are grouped by state instead of by the standard data categories of water quality, benthic habitats and associated biological communities.

*Table 13.1. Monitoring efforts across the FSM.*

| PROGRAM | OBJECTIVES | START DATE | FUNDING | PARTNERS |
|---|---|---|---|---|
| Kosrae Fish Monitoring Program | Assess stocks of commercially important food fish in Kosrae. | 2000 | NOAA, KSG | KDMS |
| Kosrae Marine Monitoring (Reef Check) | Monitor the status of the reefs of Kosrae to assess changes in coral, fish and invertebrates over time (monitoring sites increased from six to ten in 2000). | 1994 | KSG, Sea Grant, Kosrae Village Resort and Volunteer Divers, NOAA | KDMS, KVR, KCSO |
| Pohnpei MPA Monitoring Program | Monitor important fishery species for five MPA sites within Pohnpei lagoon.<br>Apply CSP's established fishery monitoring protocol to newly established MPA's within the network.<br>Continue a coral and benthic habitat monitoring program established in 2004/2005.<br>Continue monitoring of a multi-species, Serranid spawning aggregation inside the Kepahara MPA.. | 2003 | NOAA, DOI-OIA, Packard Foundation | CSP, PMRD |
| Yap State Coral Reef Monitoring Program | Establish a monitoring program with simple, realistic methods.<br>Establish a working network among agencies in Yap and in the region for collecting, processing, and sharing monitoring information.<br>Collect and use baseline monitoring data to promote and technically support conservation efforts at the community level. | 2006 | NOAA, Yap State | YapCAP, YEPA, YMRMD, |
| Chuuk Coral Reef Monitoring Program | Under development. | Planned to start in 2008 | NOAA, Chuuk State, MCT | CCS, CEPA, CMRD |

CCS = Chuuk Conseration Society
CEPA = Chuuk Environmental Protection Agency
CMRD = Chuuk Marine Resources Division
CSP = Conservation Society of Pohnpei
KCSO = Kosrae Conservation and Safety Organization
KDMS = Kosrae Division of Marine Surveillance
KIRMA = Kosrae Island Resource Management Authority
KSG = Kosrae State Government
KVR = Kosrae Village Resort Ecolodge
MCT = Micronesian Conservation Trust
PMRD = Pohnpei Marine Resources Division
YapCAP = Yap Community Action Program
YEPA = Yap Environmental Protection Agency
YMRMD = Yap Marine Resources Management Division

From 2005 to 2007, the Palau International Coral Reef Center (PICRC) and the National Oceanic and Atmospheric Administration's (NOAA) Coral Reef Conservation Program sponsored annual coral reef ecosystem monitoring workshops to build monitoring capability within Micronesia. Rob van Woesik from the Florida Institute of Technology conducted these trainings which focused on coral and fish taxonomy, reef sampling methods, experimental design, statistical analyses, data management and reporting to local and state agencies. Participants from Yap, Pohnpei, Kosrae and Chuuk attended the workshops. Ongoing coordination efforts will continue to support the first regionally-coordinated monitoring program within Micronesia. This monitoring program has been an international collaboration supported by NOAA, PICRC, the FSM Government, the Japanese International Cooperation Agency, the Marine Resources Pacific Consortium, TNC, government regulatory agencies and NGOs of Micronesia.

### Kosrae

The Division of Marine Surveillance (DMS) under the Department of Agriculture, Land and Fisheries is the lead agency that monitors Kosrae's coral reef ecosystems, with the assistance of KCSO and the Kosrae Village Ecolodge. Financial support from the U.S. Department of Interior made it possible to implement a REA in 2006. In addition, staff from DMS and KCSO participated in coral reef ecosystem monitoring workshops held in Palau and sponsored by NOAA.

The status of Kosrae's reefs is monitored annually at five permanent coral monitoring sites with an additional proposed site at a patch reef within Lelu harbor (Figure 13.12). The purpose of the coral monitoring program is to detect possible changes in benthic cover and the abundance of fish, and identify factors that may disturb the health of Kosrae's coral reef ecosystem. A diverse number of benthic habitats are found within the coral reef ecosystem of Kosrae, and it is estimated that there are more than 200 species of coral (Donaldson et al., 2007). A total of 38 species of algae have been documented in Kosrae (USACOE, 1989a).

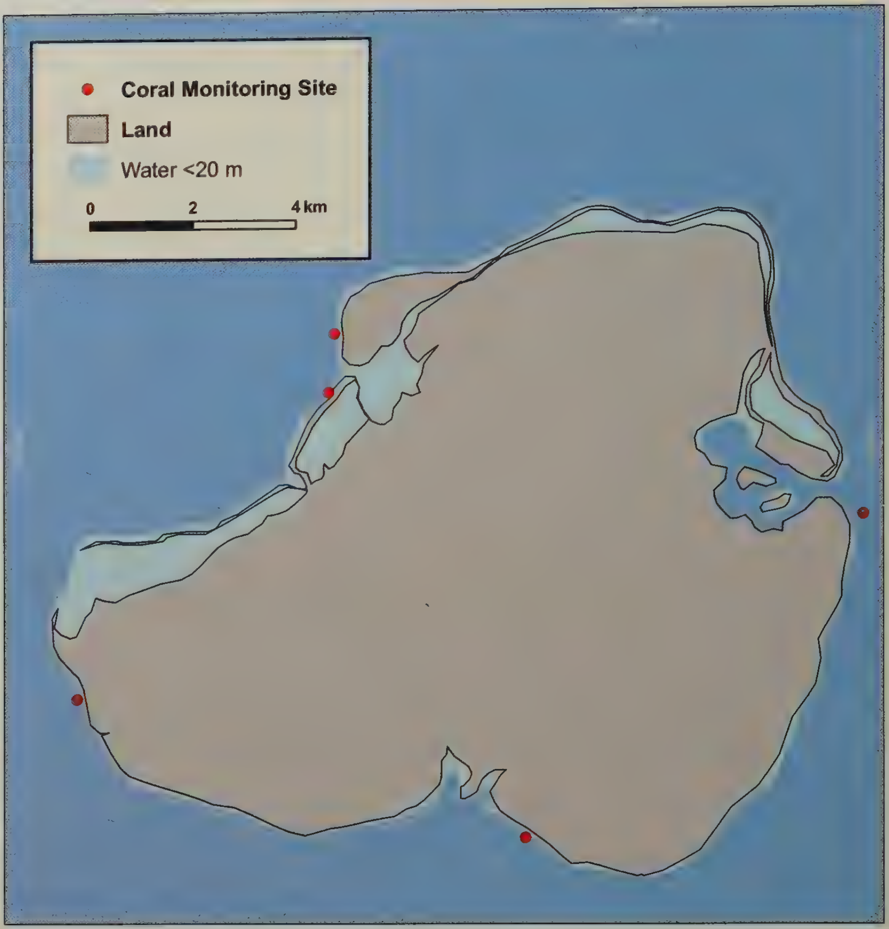


*Figure 13.12. Location of monitoring sites in Kosrae. Map: K. Buja.*

Kosrae is a steep volcanic island with high annual rainfall. Road construction, home development and land clearing are major sources of erosion and sedimentation which impact coral reefs. Based on the preliminary findings of the 2006 REA, turbidity is quite high in Okat, Utwe Bay and Lelu Harbor, especially in areas where streams and river mouths are located (Donaldson et al., 2007).

The only method that has been used by the Kosrae state coral monitoring team to carry out its monitoring activities is the Reef Check Method (http://reefcheck.org/conservation/long_term_monitoring.php). The following data are collected during each survey:

- Benthic cover at every half meter along an 80 m transect, using the line intercept method.
- Fish counts, targeting specific indicator species along a 5 m x 5 m x 80 m belt. The fish counter takes 12 minutes to swim each of the 20 m replicates.
- Invertebrate counts target indicator species along the same belt transect.
- Environmental data including wind speed and direction, cloud cover, air temperature and water temperature at the surface and at depth, and horizontal visibility.
- A water sample is collected for an analysis of salinity.
- Additionally, the environmental data collectors swim through the transect line for an overall picture of coral condition, damage, existence of marine debris, etc.
- Site information, such as the nearness of various pollution sources, amount of fishing and diving activities and the use of destructive fishing methods, is also recorded.

Traditionally, under the Reef Check protocol, transect lines are put out and then there is a 20-30 minute wait for the fish to come out of hiding. Our experience has been that while this works well with the smaller fish, larger species tend to move away from transect lines and are not counted. Beginning in 2007, the fish counter swam with the person laying out the line to record the presence of large fish. After the fish counter completed the first half of the transect, the coral, invertebrate and environmental data recorders enter the water to begin their work. Finally, the data are entered into a database, where they are analyzed and published in the Reef Check annual report.

Currently there are two separate coral monitoring programs underway, both using Reef Check protocols. Kosrae MRD and KCSO survey five sites twice per year. A program organized by the Kosrae Village Ecolodge utilizes sport divers to conduct surveys at 8-12 sites annually. Data from both programs are represented here. Types of corals observed included hard corals, soft corals, fleshy seaweeds and sponges. Surveys conducted at each site indicated a predominance of healthy corals with 40% to 60% live hard coral cover.

Surveys conducted at each coral monitoring site indicated that the status of coral reefs are in good condition, with percent cover of hard corals ranging from 64% at Inpeah, Molsron Malem; 60% at Inpucspucsah Utwe; 47% at Tukunsru Walung; 63% at Insrac Meloh Tafunsak; and 48% at Saclem Tafunsak or the Trochus Sanctuary. Other substrate components surveyed included coralline algae, dead coral, *Halimeda*, rubble, rock, sand, turf algae and others.

James Maragos, Terry Donaldson and staff from DMS and KCSO conducted REA surveys on coral and fish species in 2006 (Donaldson et al., 2007). The group split into two teams, with one focused on coral species and the other focused on fish species. Some of the common food fish recorded included blacktail snapper (*Lutjanus fulva*), blackspot emperor (*Lethrinus harak*), multibarred goatfish (*Parupeneus multifasciatus*), bullethead parrotfish (*Chlorurus sordidus*), swarthy parrotfish (*Scarus niger*), blue banded surgeonfish (*Acanthurus lineatus*) and whitecheek surgeonfish (*A. nigricans*).

The 2006 REA also indicated that some species of groupers, jacks, trevalleys, snappers, emperor, sweet lips and parrotfish were absent compared to survey conducted in 1986. There were also 59 new records of fish species seen throughout the survey that were not documented in 1986. There were a few humphead wrasse (*Cheilinus undulatus*) recorded, but no bumphead parrotfish (*Bolbometopon muricatum*). These two species of fish are considered to be very rare in Kosrae. There are approximately 500 species of fish found in Kosrae's reef, estuarine, mangrove and freshwater habitats and more than 71 species of mollusks are thought to be found in Kosrae. Out of 500 species of fish, 200 are commonly considered food fish (Figure 13.13).

*Figure 13.13. A coral grouper swimming around a fringing reef in Kosrae. Photo: K. Adams.*

Kosrae has recently limited the export of reef organisms except for personal and family use, such as shipping coolers of fish to relatives living abroad. The Kosrae Coastal Resources Inventory (KCRI) recorded 252 fish species in 1986. It also reported that more than 250 fish species are used as food fish in Kosrae (Environment Resources Section, 1989; KCRI; U.S Army Engineer District, Honolulu). The recent REA in Kosrae however estimated that there are 518 species of fish (Donaldson et al., 2007) and suggest that the total number of species occurring at Kosrae will increase with further sampling. The Kosrae REA report recommended consideration of future MPA designations in Kosrae and suggested several sites (29, 43, 36, 40 and 49) as possible choices for future MPAs.

### Pohnpei

Coral reef ecosystem monitoring in Pohnpei started in 2004. The monitoring program was recently expanded with monitoring of additional components to help coastal and marine resource managers better understand the condition of Pohnpei's coral reefs. The program currently monitors several ecosystem components: 1) grouper spawning aggregations; 2) MPA effectiveness; 3) changes in benthic communities over time; and 4) sedimentation. Methods for one through three are described in the 2005 edition of this report (Waddell, 2005). Results from these surveys are currently being analyzed.

To monitor sedimentation, the CSP, along with its partner agencies (Pohnpei State Department of Land and Natural Resources and Pohnpei State Department of Economic Affairs) are installing sediment monitoring traps adjacent to the start point of all 16 benthic monitoring sites, which use methods established by English et al. (1997). At each site, a total of three sets of sediment traps will be installed. Each set of traps will consist of three 5 cm x 11.5 cm sections of PVC pipe clustered around a central stake. Each set of traps will be anchored at a depth of 3 m below the mean low tide mark, at 1 m intervals adjacent to the start of the transect. Traps will be collected and emptied once every month during a 12 month study period. Sediment will be dried and weighed. Data collected from the sediment traps will be used to look for trends in seasonal and longer term changes in sediment load in the lagoon. Funding will be sought to continue sediment monitoring in subsequent years.

### Chuuk

The state of Chuuk is in the very early stages of establishing a long-term coral monitoring program. Ten Areas of Biodiversity Significance (ABS) comprising 20,683.29 ha in Chuuk have been identified by the FSM Blueprint (TNC, 2003), and these areas will be the basis for selecting the permanent monitoring sites. Any additional areas in need of monitoring and protection will be identified through a REA of Chuuk State and a biodiversity gap assessment for the FSM, both of which are planned for 2008.

The CCS will work with communities, Chuuk MRD, Chuuk EPA, the College of Micronesia-FSM (COM-FSM), TNC, PICRC and other partners on the proposed marine monitoring, and will also be responsible for writing and submitting the results of the project. The marine monitoring program will be established through the proposed monitoring of the three key biotic and abiotic categories of water quality, benthic habitat, and associated biological community structure that will include fish and macroinvertebrates (Figure 13.14).

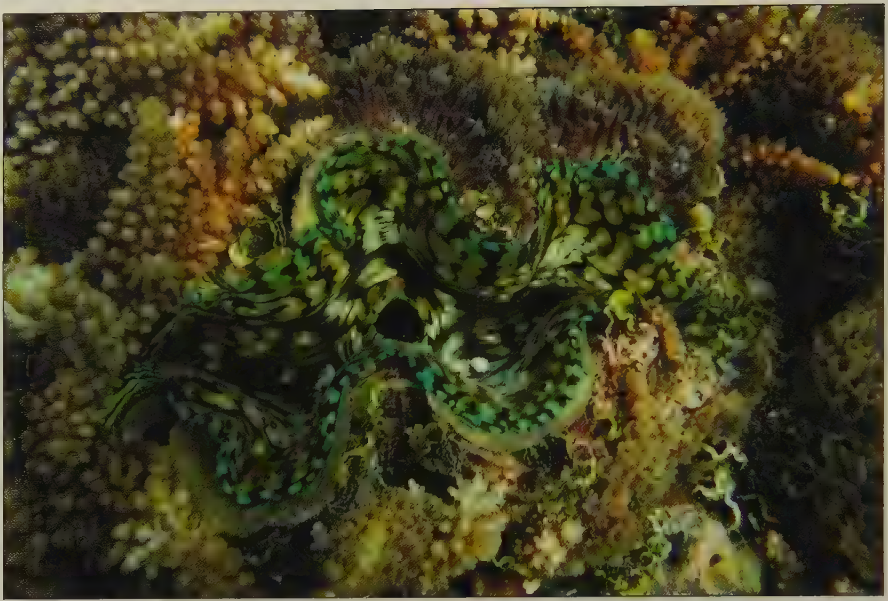


*Figure 13.14.* Tridacna *or giant clam encrusted with soft coral on the reef of Fananan Island, Chuuk. Photo: M. Gombos, PIMPAC.*

Because CCS and its partners did not attend the first two coral reef monitoring workshops in July 2005 and July 2006 held at PICRC, they are in the very early stages of development of a marine monitoring strategy. However, key staff received on-site training in establishing sites and standard monitoring methodologies during the NOAA Coral Reef Monitoring Workshop held in Chuuk in July 2007. This work resulted in the identification of 10 potential monitoring sites that were chosen to contrast outer barrier reefs with reefs inside the lagoon and reef passes. Further training in monitoring for personnel is needed (R. Osiena, pers. comm.).

### Yap

As in most of the Pacific Islands, the rich and diverse ecosystems of Yap have historically been protected for subsistence purposes by traditional resource management practices. However, given the large-scale nature of modern day resource uses and other uncontrollable factors, traditional management practices are now facing challenges. Increasingly, marine ecosystem degradation is seen around areas of development in Yap (Goldman, 1994), and coral reefs are becoming sources of major economic benefit with conflicting uses in construction, export and tourism. According to an ecological baseline assessment prepared for the International Waters Project in Yap (PICRC, 2005), live coral cover ranged from 11–56% at five proposed MPA sites. Mean density of 14 target food fish species on transects at four proposed MPA sites ranged from 7 to 24 individuals per 100 $m^2$ (PICRC, 2005).

Reef areas in Yap are all privately owned in a strong and complex system of marine tenure (Smith, 1994). In order for present-day marine resources in Yap to be sustainably managed, scientific data must be collected and incorporated into traditional knowledge and management methods. Blending science and traditional management by using and building on local capabilities has been identified as the most realistic and successful method of conservation management in the region (Kelty and Kuartei, 2004; Starmer, 2003; Pinca, 2003; Kuartei and Matthews, 2003; Richmond et al., 2002). Similar programs have been implemented locally by other governments and cultures in the region (Starmer, 2003; Pinca, 2003; Kuartei and Matthews, 2003). The Environmental Stewardship Consortium (ESC) was formed in 2001 in response to a mandate from the Council of Pilung, Yap's council of chiefs and fourth branch of government. The mission of the ESC is to link science and traditional knowledge through a network of people representing government, traditional leaders and communities.

Establishing a locally-implemented, long-term marine monitoring program is listed among the top priorities for improving natural resource sustainability efforts in Yap State and the rest of the FSM (Yap Biodiversity Strategy and Action Plan, 2004; NBSAP, 2003; FSM Economic Summit, 2003). Leaders in the FSM have also identified the need for a full representation of the status of the FSM's marine ecosystems and an evaluation of their resiliency to stress to improve understanding of FSM's marine resources (FSM Economic Summit, 2003; NBSAP, 2003).

With funding from NOAA, YapCAP initiated a monitoring program in Yap State in collaboration with the Yap EPA and Yap MRD in the latter part of 2006. The overall long-term goal of the coral monitoring program in Yap is to characterize reef community development and assess the impacts that various stressors place upon Yap's reefs, and use this information to drive management. The objectives of the program are to:

- Establish simple, realistic monitoring methods;
- Collect and analyze a set of baseline monitoring data;
- Establish a Coral Reef Task Force network among local stakeholders in marine resource management in Yap; and
- Promote and begin to provide technical support for conservation efforts at the community level.

With assistance from PICRC, Yap's coral monitoring team, which is composed of supporting agency staff and designated local community representatives, began conducting marine surveys at six sites in December 2006 to collect baseline data on benthic cover, locally and commercially valuable macroinvertebrates and fish, and coral recruitment. The Yap monitoring team plans to conduct surveys annually at the six established sites using the standard methods presented at the monitoring workshops held by PICRC and NOAA in 2005 and 2006. The general public and communities involved in this marine monitoring program will be informed about results through presentations, information sheets and other educational materials. The results of the monitoring program will also be presented to the ESC and all its members.

In addition to the long-term monitoring program, a REA was recently conducted to fill gaps in information on the marine resources of Yap State. YapCAP, with support from Packard Foundation, NOAA and TNC, coordinated a multi-disciplinary team of scientists, monitoring staff and community representatives to conduct the REA from July 11-August 2, 2007. The team surveyed 19 sites around Wa'ab, 12 sites around Ngulu Atoll and 16 sites around Ulithi Atoll. Preliminary results were presented to the Chiefs of Ngulu and Falalop, one of the main islands of Ulithi Atoll, and to the ESC.

A preliminary list of 204 confirmed coral species was compiled, with 167 from Ngulu Atoll and 180 from Ulithi Atoll (Turak, in prep.). An estimated 215 coral species were recorded on Wa'ab (Houk and Starmer, 2007). Quantitative and qualitative benthic surveys were also conducted (Houk and Starmer, 2007). Researchers recorded a total of 625 species of fish for all three locations, including 349 new range records and 91 new records for Yap State (G. Allen, pers. comm.). The total known fish fauna of Yap State now stands at 787 species in 275 genera and 76 families. Additionally, predictions of the total number of reef fish based on the number of species in six key indicator families suggest that at least 928 species can be expected to occur at Yap and outlying atolls. The team found that surveyed reefs in general are in very good condition, especially at remote Ngulu Atoll (Figure 13.15).

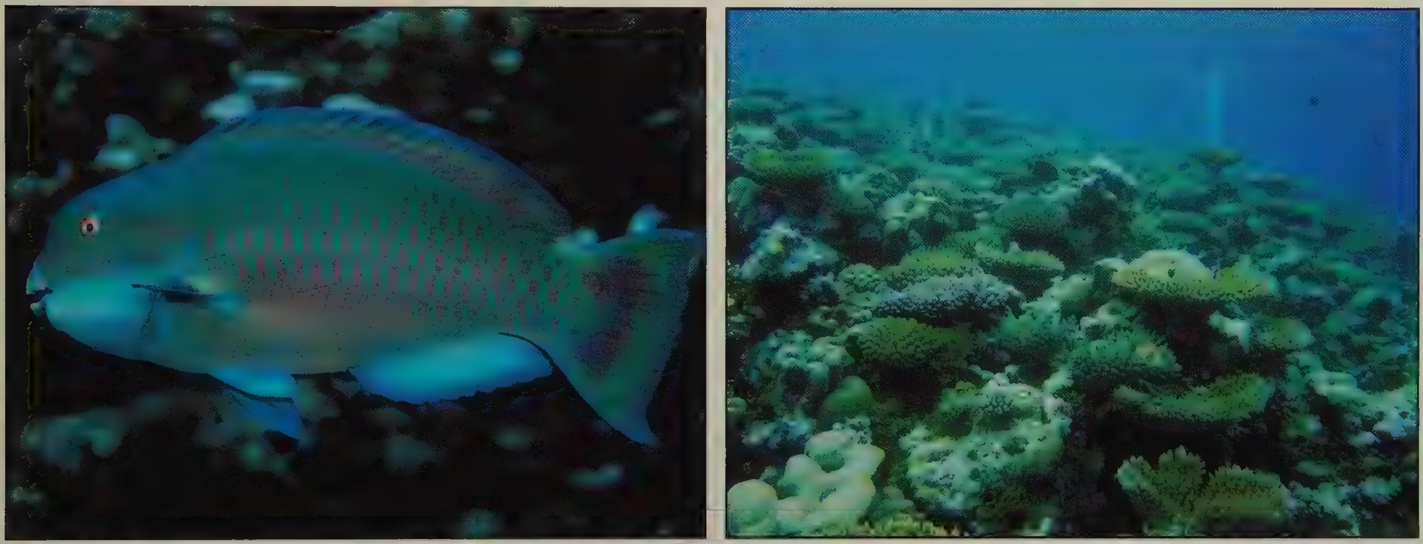


*Figure 13.15. A* Chlorurus microrhinos *in Ulithi Atoll of Yap (left). Photo: G. Allen. Ngulu Reef in Yap (right). Photo: P. Houk.*

## Overall Condition and Summary of Analytical Results

The coral reefs around Kosrae are generally in good to excellent condition (Figure 13.16). However, monitoring throughout the years has indicated some potential stressors on the coral reef ecosystems. Since Kosrae is a very small island, there is still a pressing need to have further protection in order to decrease the impacts from coastal development and other activities that contribute to soil erosion and sedimentation.

*Figure 13.16. An anemone in Kosrae provides habitat for fish. Photo: K. Adams.*

Both local coral monitoring programs and coral reef research show that Pohnpei's coral reef ecosystems have been adversely affected by sediment runoff, dredging and predation by COTS. These three major forms of disturbance together have affected species composition and the structure of coral communities (Turak and DeVantier, 2005). Sediment runoff and dredging have caused a major loss of coral cover and diversity at heavily-impacted sites, which are now covered by a layer of fine silt and have very low water clarity, hindering recovery. Results from monitoring showed little to no evidence of destructive fishing, impacts from boat anchoring or damage from SCUBA diving. Abundance of targeted species of reef fishes, particularly in the families Lethrinidae, Lutjanidae and Serranidae, appeared to be low in many areas, possibly indicating local overfishing. The lack of predators combined with nutrient enrichment from runoff in the lagoon may also be contributing to the prevalence of the COTS.

Coral reefs in Yap are in relatively good condition with diversity being among the highest in the FSM (Allen, 2007; Hasurmai et al., 2005; Kelty and Kuartei, 2004; Richmond et al., 2002). However, during recent REA surveys, there were signs of coral bleaching, COTS damage, destructive fishing from foreign poachers, and physical damage from possible storms or ship groundings. The highly threatened Napoleon wrasse (*Cheilinus undulatus*) was relatively abundant (observed at 50% of the survey sites), but with an estimated average total length for observed individuals of only 48 cm (Allen, 2007). In addition, fewer sharks than expected were seen at Ngulu Atoll, despite good reef conditions, which may indicate the presence of foreign fishers engaged in illegal shark-finning operations (Allen, 2007).

## CURRENT CONSERVATION MANAGEMENT ACTIVITIES

In 2003, the FSM completed a National Biodiversity Strategy and Action Plan (NBSAP) with the goal of protecting and sustainably managing a full representation of the country's marine, freshwater and terrestrial ecosystems. In 2003, the government of the FSM, the U.S. Forest Service, TNC, university scientists, and local experts also drafted *A Blueprint For Conserving the Biodiversity of the Federated States of Micronesia* (the FSM blueprint) in order to begin to address this goal. A total of 130 ABS including 86 coastal and marine sites comprising 260,948 ha (over 1,007 square miles) were identified nationwide (Table 13.2).

Each of the four states of the FSM is in various stages of developing protected areas networks. Pohnpei is the furthest along with 11 legal marine sanctuaries and a central Watershed Forest Reserve. Historically, there has been little national involvement in protected area establishment and management. However, the establishment of a Protected Areas Network is a high priority under the NBSAP. The NBSAP sets a clear conservation objective under the major theme of ecosystem management:

> *"A full representation of the FSM's marine, freshwater, and terrestrial ecosystems are protected, conserved and sustainably managed, including selected areas designated for total protection."*

In December 2004, a broad range of FSM partners signed the National Implementation Support Partnership (NISP) Agreement, a Memorandum of Understanding (MOU) that covers the implementation of the Convention on Biological Diversity's Programme of Work on Protected Areas. The MOU provides an overarching framework for establishing the proposed nation-wide network of protected areas. The project partners include the national government, the four state governments, the COM–FSM, Micronesia Conservation Trust (MCT), FSM Visitors Bureau, TNC, CSP, KCSO and YapCAP.

*Table 13.2. Number and size of ABS by type. Source: TNC, 2003.*

| ABS SITE TYPE | NUMBER OF ABS SITES | AREA (ha) | AREA (mi$^2$) |
|---|---|---|---|
| **TERRESTRIAL SITES** | | | |
| Yap | 3 | 651.94 | 2.52 |
| Chuuk | 9 | 4,328.06 | 16.71 |
| Pohnpei | 9 | 12,833.28 | 49.53 |
| Kosrae | 2 | 4,835.04 | 18.66 |
| Total Terrestrial | 23 | 22,648. 32 | 87.42 |
| **MARINE ONLY SITES** | | | |
| Yap | 6 | 49,471.10 | 190.95 |
| Chuuk | 10 | 20,683.29 | 79.83 |
| Pohnpei | 5 | 12,480.50 | 48.17 |
| Kosrae | 1 | 54.52 | 0.21 |
| Total Marine | 22 | 82,689.39 | 319.17 |
| **COASTAL MARINE SITES** | | | |
| Yap | 21 | 24,007.43 | 92.66 |
| Chuuk | 20 | 77,089.91 | 297.55 |
| Pohnpei | 18 | 75,695.26 | 292.17 |
| Kosrae | 5 | 1,466.07 | 5.66 |
| Total Coastal Marine | 64 | 178,258.67 | 688.04 |
| **COASTAL FRESHWATER SITES** | | | |
| Yap | 2 | 31.76 | 0.12 |
| Chuuk | 11 | 936.66 | 3.62 |
| Pohnpei | 3 | 5,283.09 | 20.39 |
| Kosrae | 4 | 1,904.89 | 7.35 |
| Total Coastal Freshwater | **20** | **8,156.39** | **31.48** |
| **Overall Total** | **130** | **291,752.77** | **1,126.11** |

Over the past several years, Kosrae has started to develop a MPA program that involves co-management of coastal resources between local communities and state resource management agencies. Currently, Kosrae has five conservation areas that are managed by government agencies and/or local communities. These are: the Utwe-Walung Marine Park, Utwe Biosphere Reserve, the Awane Marine Park and Areas of Special Concern, such as the Trochus Sanctuary and the Okat-Yela Mangrove Reserve. After completing the community consultation for planning and establishment of Utwe Biosphere Reserve, KCSO also launched a community consultation with the community of Tafunsak for planning and establishing a marine protected area there. There is also a proposed marine park in Malem. The Utwe Biosphere Reserve is a community-based project established in 2002 and is the FSM's first biosphere reserve. Utwe Biosphere Reserve is located within the Utwe-Walung Marine Park. The Utwe Biosphere Reserve was created to protect and conserve the resources within the area and to provide opportunities for public education and scientific research. The Utwe-Walung Marine Park was created in 1996 to protect extensive mangrove and coral reef ecosystems along the undeveloped southern shore of Kosrae. The Marine Park is also a community-based project managed by a board of directors, a park manager, and landowners, with assistance from conservation agencies and organizations in Kosrae. The Marine Resources Act of 2000 (Kosrae State Code, Title 19) is enforced by the DMS, public safety department and the Kosrae Island Resource Management Authority as the Kosrae State government regulatory agency. Environmental awareness activities have been carried out within the community and the schools to help support and strengthen the conservation effort in Kosrae. KCSO also developed and implemented an environmental awareness program entitled the *Friday Radio Spots*. This program airs important information about different ecosystems, the threats they face, and the solutions to reverse negative impacts. Kosrae also has an extensive system of 54 mooring buoys around the island designed to minimize anchor damage to corals at popular dive sites.

Chuuk communities have begun conservation work in several ABS, including the Parem Totiw Marine Area ABS, the Wichap-Epinup-Peidiu-Nukanap Mangrove and Marine area ABS and the Polle Piannu Pass Grouper spawning area ABS. These ABS sites are at different stages in management planning, but all need reliable scientific monitoring data to help determine the status of the resources and the effectiveness of current management activities. The data gathered will be disseminated to communities through awareness programs and school presentations to promote interest in MPA management, specifically for coral reefs, and the expansion of the MPA network.

Because life in Chuuk remains very traditional, several chiefs have implemented protective measures for specific conservation purposes, such as the protection of a turtle nesting site at Nomun Weito and implementation of a no-take area in the Halls region (R. Oseina, pers. comm.). The effectiveness of traditional management strategies in Chuuk encourages other communities to adopt such measures.

In Yap State, there is currently one MPA set up on Wa'ab, a Locally Managed Marine Area (LMMA) with 25.9 ha (0.1 mi$^2$) of reef set aside by Riken community. In addition, YapCAP is working with the communities of Qokaaw and Kadaay on the Nimpal Channel LMMA and Maaq and Lebinaw on the Peelaek Channel LMMA.

At the Eighth Conference of the Parties to the Convention on Biological Diversity held in March 2006 in Curitiba, Brazil, TNC co-hosted a high-level event where the leaders of the five political entities of Micronesia (Republic of Palau, Federated States of Micronesia, Republic of the Marshall Islands, Commonwealth of the Northern Mariana Islands and Guam) announced the Micronesia Challenge to the international community.

The program challenges Chief Executives of Micronesia to:

- Sustain unique island biodiversity;
- Ensure a healthy future for island people;
- Protect unique island cultures;
- Guard pristine island environments, the foundations of their future development
- Sustain the livelihoods of island communities;
- Contribute to global and national targets set out in the Millennium Development Goals, the Johannesburg Plan of Implementation for the World Summit on Sustainable Development, the Mauritius Strategy for Small Island Developing States, the U.S. Coral Reef Task Force National Plan of Action and the relevant Programmes of Work of the Convention on Biological Diversity; and
- Agree to undertake an expanded commitment to preserve marine and terrestrial environments by *"... Effectively conserving at least 30% of the near-shore marine resources and 20% of the terrestrial resources across Micronesia by 2020."*

The signatories to the FSM NISP have fully embraced the Micronesia Challenge as a means to leverage financial, technical and community support for the establishment of the FSM Protected Areas Network (PAN). In early 2006 a core team, comprised of key FSM government and regional NGO members, was formed to guide establishment of the FSM PAN. The NISP signatories and core team, in particular the local conservation NGOs, have taken the lead on engaging members of the community to garner support for the FSM PAN and the Micronesia Challenge, resulting in a range of actions such as a legislative resolution in Kosrae and calls for traditional protected areas in Yap. From, January 2005 to March 2007, core team members conducted a total of 13 state visits to provide marine technical assistance, introduce the concept of the PAN and the Micronesia Challenge and promote participation. In October 2006, the first FSM Environment Conference was held in Pohnpei and included sessions on the PAN and Micronesia Challenge. A large delegation from the FSM, including representatives from all four states and the national government attended the first regional Micronesia Challenge action planning meeting in Palau in December 2006. Through the Micronesians in Island Conservation Network and state site visits, TNC continues to assist local partners in their efforts to build consensus for the network from the bottom up, beginning with communities.

In addition, NGOs and government agency partners have helped communities with existing protected areas to do site-based planning activities. Conservation Action Plans have been developed for four high priority sites that will be part of the protected areas system: Kosrae Yela Terminalia Forest, Pohnpei Watershed Forest Reserve, Pohnpei Lagoon and Kosrae Utwe-Walung Biosphere Reserve.

In 2006 MCT began co-coordinating the Pacific Islands MPA Community (PIMPAC). PIMPAC is a NOAA-funded initiative to support MPA development and management work. Thus far PIMPAC has provided capacity building support to MPA managers and organizations throughout the FSM and Micronesia. This support includes trainings on developing MPA management plans, project design, fundraising, grants and report writing and learning exchanges. PIMPAC conducted a management planning workshop in October 2006 (Figure 13.17). Sixteen FSM resource managers and conservation practitioners who are involved in MPA management participated (Figure 13.18). These managers are actively working on management plans for pilot sites in their islands. The PIMPAC resource team has been providing follow-up specific to each state's needs.

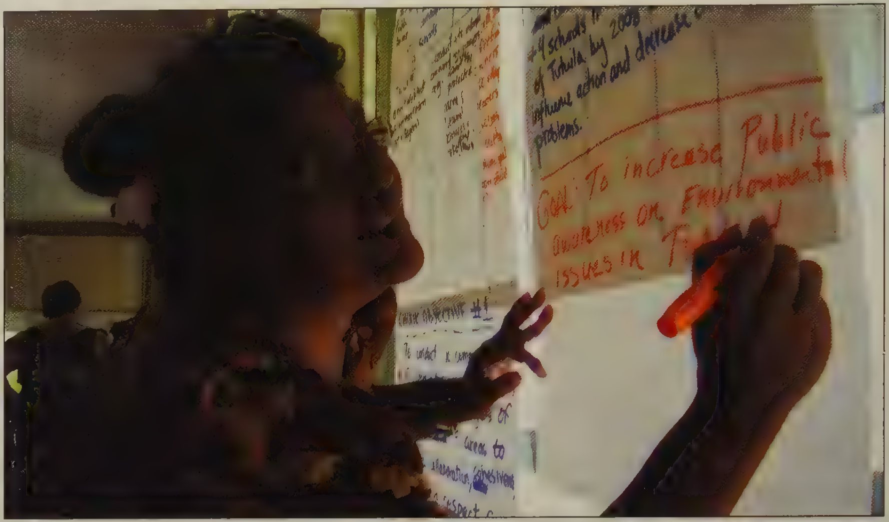

Goal: To increase Public awareness on Environmental issues in T

Figure 13.17. Julita Albert of Chuuk EPA noting UFO, Fefan MPA Goal at Pacific Islands MPA Community Regional MPA Management Planning Workshop in Chuuk, October 2006. Photo: D. Wusinich-Mendez, PIMPAC.

Figure 13.18. The Pohnpei group pictured deep in discussion (left). Participants from 'UFO', which stands for the island of Fefan's three villages of Unuuno, Fongen, Onongoch, working together to identify management priorities (right) at the PIMPAC MPA management planning workshop in Chuuk, October 2006. Photos: M. Gombos, PIMPAC.

Finally, in order to address critical capacity needs in the FSM and the rest of the region, an internship program was established with support from the Pew Fellowship in Marine Conservation, NOAA and TNC in 2006. Conservation "champions" in each of the five island jurisdictions are assisting with outreach and education aspects of the Micronesia Challenge. These champions will be housed in a focal point organization or agency within each island jurisdiction. Champions will be mentored by Willy Kostka, a 2006 Pew Fellow for Marine Conservation and the executive director of MCT, PAN Coordinators from the FSM, Palau and the Marshall Islands, TNC staff, and senior staff from each focal point agency. The mentors will assist the champions in developing and implementing Micronesia Challenge outreach campaigns and professional development plans.

## And Atoll Declared A Biosphere Reserve

In 2007, the And Atoll Biosphere Reserve was established as the first United Nations Educational, Scientific and Cultural Organization (UNESCO) Biosphere Reserve in the state of Pohnpei (Figure 13.19). It is also Pohnpei's first government and private landowner co-managed MPA. Sanctioned by the Bureau of the International Coordinating Council of UNESCO's Man and the Biosphere Program, Biosphere Reserves are areas set aside to illustrate proven conservation methods designed to sustain the area's ecosystems. In September 2007, UNESCO added 23 new reserves sites in 18 countries to its global network of more than 500 reserves.

In 2002, the Conservation Society of Pohnpei and UNESCO's Pacific office began working together to establish And Atoll as a biosphere reserve. In the process of petitioning for Biosphere Reserve status, it was determined that more fieldwork, assessment and discussion were required to gain the information needed to complete the application for submission. A REA was conducted in July 2006, which revealed And Atoll is one of the most biologically significant areas in Pohnpei State.

Due to its isolation and lack of human occupation for more than 20 years, And Atoll had already been established as Pohnpei's number one marine Area of Biodiversity Significance and a Priority Action Area (Figure 13.20). And Atoll retains one of the last relatively intact seabird rookeries in the region and provides crucial nesting grounds for rare sea turtles. The atoll's main channel has also been identified as one of the few grouper spawning and aggregation sites on Pohnpei. And Atoll is also home to the healthiest giant clam population in the state, and attracts aggregations of sharks, barracudas and other marine life.

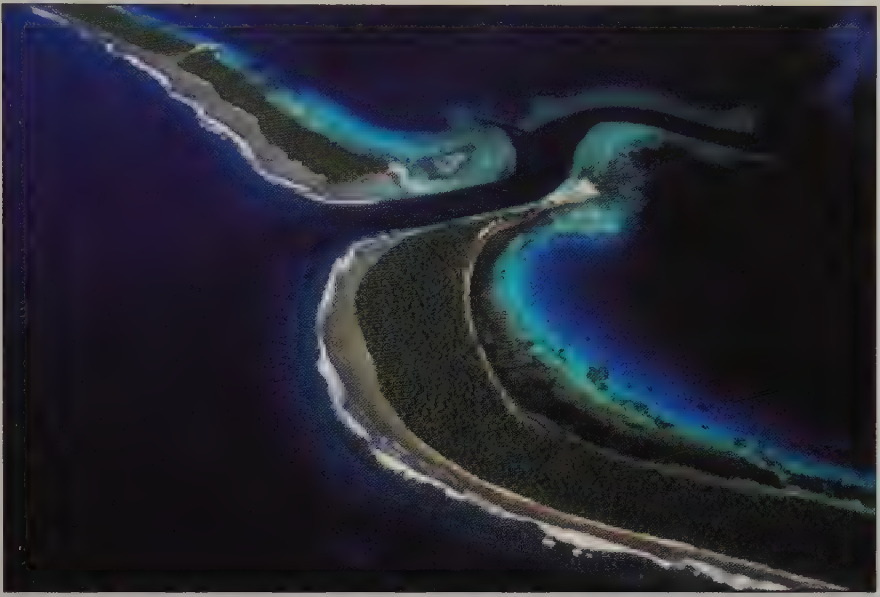


*Figure 13.19. Aerial view of a reef pass at And Atoll. Photo: J. O'Hare.*

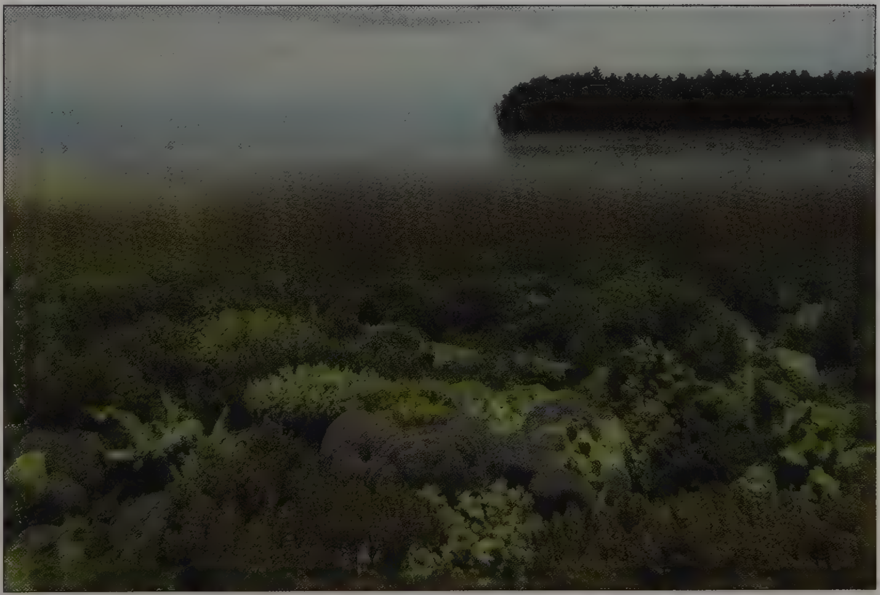


*Figure 13.20. And Atoll in Pohnpei was declared a UNESCO Biosphere Reserve in 2007. Photo: E. Joseph.*

Over-fishing, bird and turtle hunting and egg collection have become major threats to And Atoll. Achieving the status of biosphere reserve is an important initial step to protect and conserve these resources. Biosphere reserves include three zones: 1) core zones: commonly known as "no-take" areas; 2) buffer zones: allow certain, restrictedive activities; and 3) transition zones: where human settlements are located and most activities such as agriculture, fishing, logging and mining are allowed. The core zones of And Atoll Biosphere Reserve serve as models for Pohnpei's existing MPAs, where fishing and/or taking of marine life is not allowed.

## OVERALL CONCLUSIONS AND RECOMMENDATIONS

The FSM depends heavily on coral reefs for food and revenue derived from fish sales to local markets, diving and other tourism activities in marine areas (Figure 13.21). But there are many challenges facing FSM reefs ranging from local threats, such as overharvest of fishery resources and impacts from land-based activities, to global threats associated with climate change, warming temperatures and ocean acidification. The country has been experiencing the erosion of traditional management systems as well. These threats have led to a general decline in the condition of coral reef resources, especially near population centers.

*Figure 13.21. This school of rainbow runners in Pohnpei is a valuable marine resource for both dive tourism and fisheries. Photo: E. Turak.*

However, in the past 10 years, the FSM has made significant commitments at many levels to try and reverse this trend. Communities have sought assistance from local conservation NGOs and government agencies to blend traditional management practices, science, and new technologies to begin the process of building an ecologically-connected, resilient system of protected areas from the bottom up. High level leadership and political will, illustrated by such commitments as those made under the Convention on Biological Diversity and the Micronesia Challenge, have supported these grass roots efforts at the state level. Regional support from agencies and organizations including NOAA, the Department of the Interior's Office of Insular Affairs, SPREP, TNC, LMMA, Conservation International and MCT continue to provide technical and financial assistance for local implementation efforts.

Unfortunately, for a country encompassing an estimated 14,517 km$^2$ of coral reefs (Rohmann et al., 2005), additional funds for conservation efforts, including monitoring, are critically needed. In the latter part of 2006, the FSM began a process, with assistance from MCT and TNC, to develop a sustainable financing plan for establishing, implementing, maintaining and monitoring a Protected Areas Network and to achieve the goals of the Micronesia Challenge. Preliminary costs and revenues for effectively managing at least 30% of nearshore marine resources and at least 20% terrestrial resources in a nation-wide protected areas network have been identified by each state and final total costs and revenues are currently being calculated. Once these are determined, strategies to fill the gaps will be developed and implemented.

A recently completed threats and needs assessment (Kostka and Gavitt, 2006) included a number of recommendations to address some of these problems. In March 2007, MCT signed a two year contract with Timothy Fenlon and Donna Wrembeck to carry out these recommendations. The team will carry out the following in all four FSM states:

- Develop a MOU between Public Safety and agencies involved in managing natural resources for each state;
- Conduct a review of the current state and (if applicable) national statutory provisions and enforcement policies;
- Undertake enforcement assessments;
- Develop and deliver appropriate training on development;
- Develop a monitoring and evaluation format.

The project is progressing very well and has begun to yield tangible outcomes, including MOUs signed between relevant stakeholders to jointly carry out resource management activities.

Although the FSM has made a great deal of progress toward effective management and monitoring of their vast coral reef resources in the past few years, many challenges still remain. Additional priorities to continue to strengthen management and protection of coastal marine resources in the FSM include establishing new community-based MPAs for critical reef habitat, completing a REA for Chuuk and a gap assessment for ABS of the FSM, completing a capacity needs assessment for the PAN, and determining baselines and developing indicators for measuring management effectiveness toward achieving the goals of the Micronesia Challenge.

## REFERENCES

Allen, G.R. Tropical Reef Research. Roleystone, Australia. Personal Communication.

Allen, G.R. 2005. Reef Fishes of Pohnpei, Federated States of Micronesia. Final Report prepared for the Pohnpei Rapid Ecological Assessment. Conservation Society of Pohnpei. Pohnpei, Federated States of Micronesia. 19 pp.

Allen, G.R. 2007. Reef Fishes of Yap, Federated States of Micronesia. Final Report prepared for the Yap Rapid Ecological Assessment. Yap Community Action Program. Yap, Federated States of Micronesia. 21 pp.

Donaldson, T.J., J. M. Maragos, M Luckymis, S. Palik, and O. Nedlic. 2007. Coral and fish surveys at Kosrae Island, July-August 2006, Federated States of Micronesia: a Preliminary Report prepared for the Kosrae Rapid Ecological Assessment. Prepared for Kosrae Conservation and Safety Organization and The Nature Conservancy. Pohnpei, Federated States of Micronesia. 36 pp.

Eldredge, L. Bishop Museum. Honolulu, HI. Personal communication.

English, S., C. Wilkinson and V. Baker. 1997. Survey manual for tropical marine resources, 2nd edition. Australian Institute of Marine Science. Townsville, Australia. 390 pp.

Falanruw, M.C. 2004. Pacific Canaries. In: Seas, Oceans and Small Islands. Our Planet: The magazine of the United Nations Environment Programme (UNEP). 15(2) online access only. http://www.ourplanet.com/imgversn/151/falanruw.html.

FSM Division of Statistics. http://www.spc.int/prism/country/FM/stats/.

FSM Economic Summit. 2003. 3rd FSM Economic Summit. Draft Section Paper, Environment. College of Micronesia, FSM. Palikir, Pohnpei, Federated States of Micronesia.

Goldman, B. 1994. Environmental management in Yap, Caroline Islands: Can the dream be realized? Mar. Poll. Bull. 29: 42-51.

Hasurmai, M., E. J. S. Palik, and K. Rikim. 2005. The State of Coral Reef Ecosystems of the Federated States of Micronesia. pp. 387-398. In: J. Waddell (ed.), The State of Coral Reef Ecosystems of the United States and Pacific Freely Associated States: 2005. NOAA Technical Memorandum NOS NCCOS 11. Silver Spring, MD. 522 pp.

Houk, P. and J. Starmer. 2007. Rapid ecological assessment for Yap, Ngulu, and Ulithi, Yap State, Federated States of Micronesia: quantitative assessments of coral-reef assemblages and macroinvertebrate abundances. Yap Action Community Program. Yap, Federated States of Micronesia. 43 pp.

Kelty, R., J. Kuartei , Abraham, T., M. Beger, D. Burdick, E. Cochrane, P. Craig, G. Didonato, D. Fenner, A. Green, Y. Golbuu, J. Gutierrez, M. Hasurmai, C. Hawkins, P. Houk, D. Idip, D. Jacobson, E. Joseph, T. Keju, J. Kuartei, S. Palik, L. Penland, S. Pinca, K. Rikim, J. Starmer, M. Trianni, S. Victor and L. Whaylen. 2004. "Status Of The Coral Reefs In Micronesia And American Samoa." pp 381-410. In: C. Wilkinson (ed.). Status of coral reefs of the world: 2004. Volume 2. Australian Institute of Marine Science, Townsville, Australia.

Kostka, W. and Gavitt, J.D. 2006. A threats- and needs- assessment of coastal marine areas in the states of Kosrae, Chuuk and Yap, Federated States of Micronesia. Conservation Society of Pohnpei. Pohnpei, Federated States of Micronesia. 117 pp.

Kuartei, J and E. Matthews. 2003. Improving resource monitoring and increasing local participation in marine conservation areas in Palau, Micronesia. Theme 05. Second International Tropical Marine Ecosystems Management Symposium (ITMEMS 2), Manilla, Philippines. March 24-27, 2003.

Lindsay, S.R. and A. Edward. 2000. Coral Reef Status Report for the Federated States of Micronesia. College of Micronesia publication. Pohnpei, Federated States of Micronesia. 29 pp.

Maragos, JE. 1993. Impact of coastal construction on coral reefs in the U.S. Affiliated Pacific Islands. Coast. Manage. 21: 235-269.

National Biodiversity Strategic Action Plan (NBSAP) for the FSM. 2003. http://www.fsmgov.org/biodiv02.pdf.

Orcutt, A.M., R. Cordy, P.J. Rappa, and B.D. Smith. "Yap Proper Coastal Resource Inventory." 1989. Pacific Ocean Division, U.S. Army Corps of Engineers. Ft. Shafter, HI. 356 pp.

Osiena, R. Director, Chuuk Department of Marine Resources. Chuuk, Federated States of Micronesia. Personal communication.

Palau International Coral Reef Center. 2005. International Waters Project for Yap State: Ecological Base Assessment. Koror, Palau. 44 pp.

Pinca, S. 2003. Experience of community-based surveys and marine reserves in the Marshall Islands. Second International Tropical Marine Ecosystems Management Symposium (ITMEMS 2). Theme 01. Manilla, Philippines. March 24-27, 2003.

Richmond, R., R. Kelty, P. Craig, C. Emaurois, A. Green, C. Birkeland, G. Davis, A. Edward, Y. Golbuu, J. Gutierrez, P. Houk, N. Idechong, J. Maragos, G. Paulay, J. Starmer, A. Tafileichig, M. Trianni, and N. Vander Velde. "Status of the coral reefs in Micronesia and American Samoa: U.S. Affiliated and Freely Associated Islands in the Pacific." pp. 217-236. In: C. Wilkinson (ed.). Status of the coral reefs of the world: 2002. Volume 2. Australian Institute of Marine Science, Townsville, Australia. 380 pp.

Rohmann, S.O., J.J. Hayes, R.C. Newhall, M.E. Monaco, and R.W. Grigg. 2005. The area of potential shallow-water tropical and subtropical coral ecosystems in the United States. Coral Reefs 24(3): 370-383.

Smith, A. 1994. "Using Customary Practices in Marine Resource and Costal Management in Yap State, FSM." Workshop: People, Society, and Pacific Islands Fisheries Development and Management. 9-17 pp.

South Pacific Regional Environment Programme (SPREP). 1993. Nationwide Environmental Management Strategies (NEMS) – The Federated States of Micronesia. South Pacific Regional Environment Programme Publication. Apia, Samoa. 154 pp.

Starmer, J. 2003. A Case Study of the Commonwealth of the Northern Mariana Islands Marine Monitoring Program (Successes and Failures). Coastal Resources Management Office, Saipan, CNMI. http://www.icriforum.org/itmems/presentations/T5_CNMIJStarmer.doc.

The Nature Conservancy. 2003. A Blueprint for Conserving the Biodiversity of the Federated States of Micronesia. Micronesia Office, The Nature Conservancy. Arlington, VA. 104 pp.

Turak, E. Coral Reef Monitoring, Ecology and Conservation. Cergy, France. Personal communication.

Turak, E. and L. DeVantier. 2005. Reef-building corals and Coral Communities of Pohnpei, Federated States of Micronesia: Rapid ecological assessment of biodiversity and Status. Conservation Society of Pohnpei. Pohnpei, Federated States of Micronesia. 103 pp.

Turak, E. and L. DeVantier. 2007. Reef-building corals and coral communities of Ngulu and Ulithi Atolls and adjacent reefs, Yap, Federated States of Micronesia: rapid ecological assessment of biodiversity and status. Final Report for the Yap Community Action Program. Yap, Federated States of Micronesia. 62 pp.

U.S. Army Corps of Engineers (USACE). 1985. Pohnpei Coastal Resource Atlas. Manoa Mapworks, Honolulu, Hawaii. Pacific Coast Division, U.S. Army Corps of Engineers. Fort Shafter, HI. 78 pp.

U.S. Army Corps of Engineers (USACE). 1986. Pohnpei Coastal Resource Inventory. Pacific Ocean Division, U.S. Army Corps of Engineers. Fort Shafter, HI. 170 pp.

U.S. Army Corps of Engineers (USACE). 1987. Kosrae Coastal Resource Atlas. Manoa Mapworks, Pacific Ocean Division, U.S. Army Corps of Engineers. Fort Shafter, HI. 61 pp.

U.S. Army Corps of Engineers (USACE). 1988. Yap Coastal Resource Atlas. Manoa Mapworks. Honolulu, HI. 67 pp.

U.S. Army Corps of Engineers (USACE). 1989a. Kosrae Coastal Resource Inventory. Pacific Ocean Division, U.S. Army Corps of Engineers. Fort Shafter, HI. 187 pp.

USACE, Pacific Ocean Division. 1989b. Yap Islands Coastal Resource Inventory. Pacific Ocean Division, U.S. Army Corps of Engineers. Fort Shafter, HI. 355 pp.

U.S. Department of Interior (USDOI). Office of Insular Affairs, Compact Grants- FSM. http://www.doi.gov/oia/Firstpginfo/compactgrants/index.html.

Waddell, J.E. (ed.). 2005. The State of Coral Reef ecosystems of the United States and the Pacific Freely Associated States: 2005. NOAA Technical Memorandum NOS NCCOS 11. Silver Spring, MD. 522 pp.

Yap State Environmental Stewardship Consortium. 2004. Yap Biodiversity Strategy and Action Plan. 26 pp.

# The State of Coral Reef Ecosystems of the Commonwealth of the Northern Mariana Islands

John Starmer[1], Jacob Asher[7,8], Fran Castro[2], Deborah Gochfeld[3], Jamison Gove[7,8], Amy Hall[7,8], Peter Houk[2], Elizabeth Keenan[4], Joyce Miller[7,8], Robert Moffit[7,8], Marc Nadon[7,8], Robert Schroeder[7,8], Ellen Smith[7,8], Michael Trianni[6], Peter Vroom[7,8], Kevin Wong[7] and Kathy Yuknavage[1]

Contributors: Clarissa Bearden[2], Rodney Camacho[2], Jean Duenas[1], Ben Richards[7,8], Roy Tsuda[5] and Brian Zgliczynski[7]

## INTRODUCTION AND SETTING

This report is the third in a series of assessments of the current status of coral reef ecosystems in the U.S. Commonwealth of the Northern Mariana Islands (CNMI) and complements other previous assessments. The focus of this report is primarily on data collected during the period 2004 through 2007, with a greater emphasis on oceanographic data than was found in prior reports (Figure 14.1). For general overview of individual islands, please reference Starmer et al., 2005 (http://ccma.nos.noaa.gov/ecosystems/coralreef/coral_report_2005/).

The fourteen islands that make up CNMI lie in the western Pacific basin, stretching approximately 600 km (375 miles) on a north-south axis, with the Pacific Ocean on the east side and the Philippine Sea on the west (Figure 14.2). The southern islands of the archipelago, Saipan, Tinian, Aguijan and Rota, are uplifted limestone whereas the northern islands are volcanic. Active volcanoes exist on Anatahan, Pagan and Agrihan where most recently an eruption was noted on Anatahan in 2003. The archipelago has a peak elevation of 965 m (3,166 ft) on Agrihan.

The primary ocean current that influences this region is the North Equatorial Current, flowing east to west in the tropical Pacific Ocean (Figure 14.1). Persistent trade winds (10-15 mph on average) from the east-northeast create wind driven waves that bathe the exposed shores for the majority of the year. The CNMI has a hot and humid tropical climate, with a mean annual temperature of 83°F (28.3°C) and mean annual rainfall of 84 inches (213 cm). The dryer, winter season generally extends from December through June while the wetter summer season begins in July and ends in November. The seasonality of this region varies from year to year and is influenced by El Niño Southern Oscillation (ENSO) events in the Pacific.

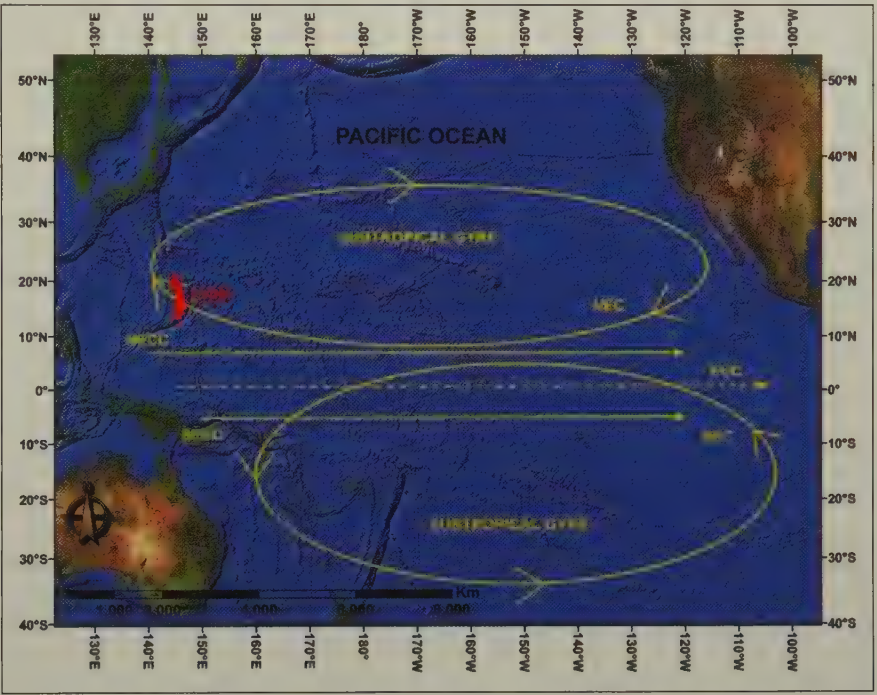


Figure 14.1. Topographic map showing location in Pacific Ocean of the U.S. CNMI and the major ocean currents in the region North Equatorial Current, South Equatorial Current, North Equatorial Counter Current, South Equatorial Counter Current and the Equatorial Under Current. Source: PIFSC-CRED.

---

1. CNMI Coral Reef Management Office
2. CNMI Department of Environmental Quality
3. University of Mississippi
4. Papahanaumokuakea Marine National Monument
5. Bishop Museum
6. CNMI Division of Fish and Wildlife
7. NOAA Pacific Islands Fisheries Science Center, Coral Reef Ecosystem Division
8. Joint Institute for Marine and Atmospheric Research

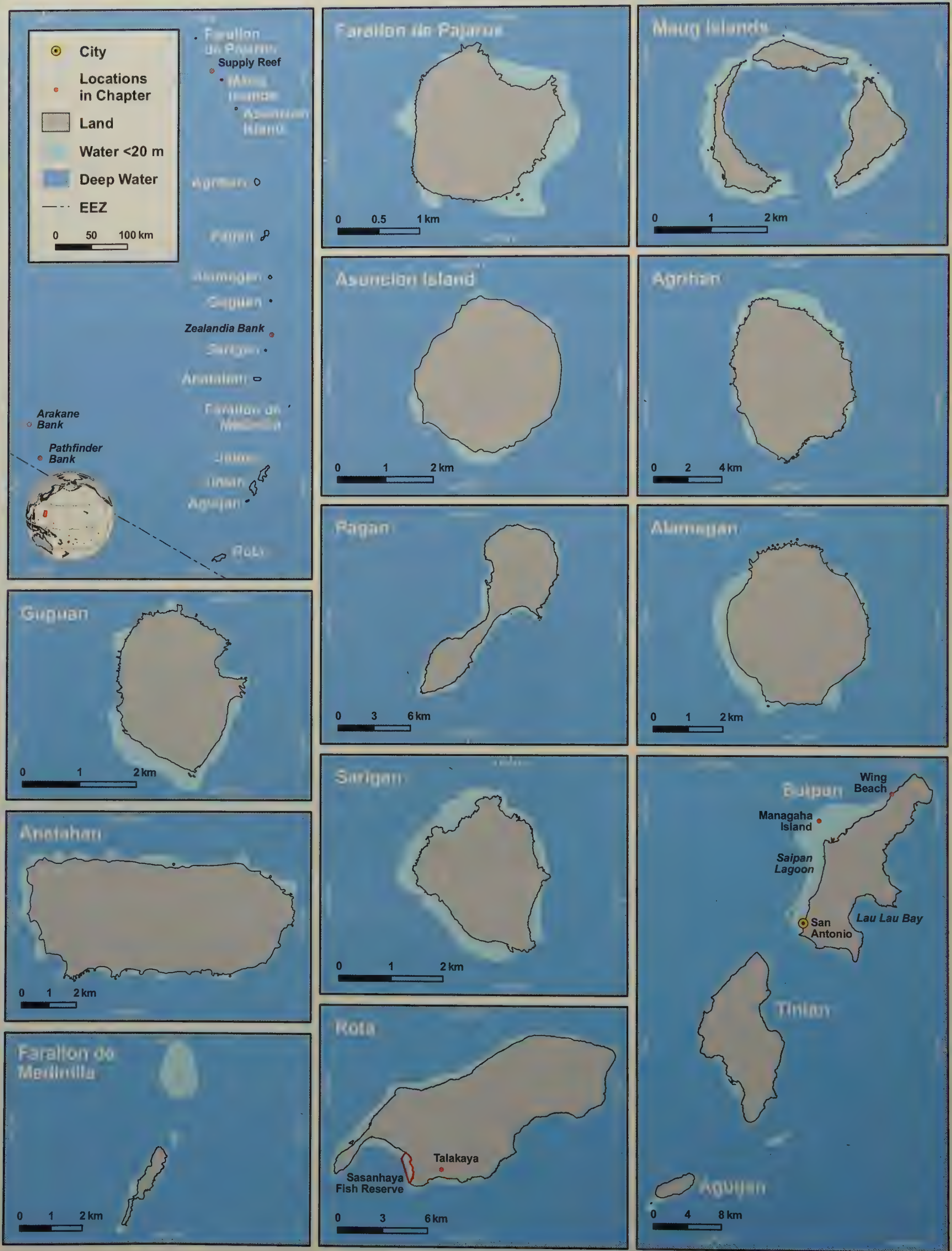

City
Locations in Chapter
Land
Water <20 m
Deep Water
EEZ
0 50 100 km
Farallon de Pajaros
Supply Reef
Maug Islands
Asuncion Island
Agrihan
Pagan
Alamagan
Guguan
Zealandia Bank
Sarigan
Anatahan
Farallon de Medinilla
Arakane Bank
Pathfinder Bank
Saipan
Tinian
Aguijan
Rota
Farallon de Pajaros
0 0.5 1 km
Maug Islands
0 1 2 km
Asuncion Island
0 1 2 km
Agrihan
0 2 4 km
Pagan
0 3 6 km
Alamagan
0 1 2 km
Guguan
0 1 2 km
Sarigan
0 1 2 km
Anatahan
0 1 2 km
Farallon de Medinilla
0 1 2 km
Rota
Talakaya
Sasanhaya Fish Reserve
0 3 6 km
Saipan
Wing Beach
Managaha Island
Saipan Lagoon
San Antonio
Lau Lau Bay
Tinian
Aguijan
0 4 8 km

Figure 14.2: A map of CNMI showing the locations mentioned in this chapter. Map: K. Buja.

# ENVIRONMENTAL AND ANTHROPOGENIC STRESSORS

## Climate Change and Coral Bleaching

Concerns over the local effects of global climate change have heightened in CNMI since a 2001 bleaching event affected shallow-water coral assemblages in the southern Mariana Islands. Gathering data relevant to the effects of global warming, such as ENSO related changes and ocean acidification, are among recently identified priorities. CNMI's resource management agencies monitoring programs are building from an ecological monitoring base to increase emphasis on monitoring water quality, oceanographic conditions, and shoreline change. Scientists are actively partnering with regional and global environmental monitoring programs such as NOAA's Integrated Coral Observing Network/Coral Reef Early Warning System (ICON/CREWS) and the National Office for Integrated and Sustained Ocean Observations. NOAA's Pacific Islands Fisheries Science Center, Coral Reef Ecosystem Division (PIFSC-CRED) maintains sea surface temperature (SST) buoys at several islands in the archipelago, and the local government also monitors sea temperature at several locations. A notable setback to local data-gathering infrastructure was the removal of a NOAA Coral Reef Early Warning System buoy due to reduced program funding at PIFSC-CRED. The CNMI government now is actively pursuing replacement of this monitoring system's capabilities through the ICON/CREWS program.

### *Coral Bleaching*

The manifestations of ENSO events have been linked to large-scale mortality of reef-building corals due to increased water temperatures and ultraviolet exposure (Hoegh-Guldberg, 1999). The CNMI lies within an ENSO core region in the western North Pacific basin that is linked to interannual variations of rainfall, with the CNMI exhibiting drought-like conditions in years following El Niño events. During El Niño years, there is an increased probability that tropical cyclones will form in the vicinity of the CNMI (http://www.soest.hawaii.edu/MET/Enso/peu/2006_4th/current_conditions.htm). ENSO events also affect local sea levels in the CNMI region with the mean sea level dropping during an El Niño period and rising above normal during a La Niña period. When comparing satellite-derived SST from CNMI with the Multivariate ENSO index, it appears that during a strong El Niño (e.g., 1997-1998), maximum annual temperatures at Maug, Pagan and Saipan are cooler than average when compared to non El Niño years (Figure 14.3).

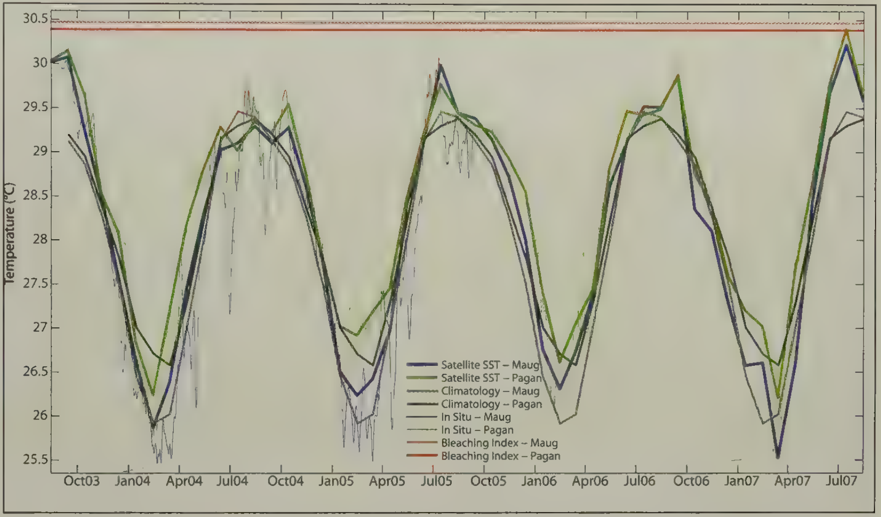


*Figure 14.3. Relationship between NOAA Pathfinder derived SST at Maug, Pagan and Saipan (top) and the Multivariate ENSO Index (MEI; bottom) from 1985-2006. Source: PIFSC-CRED.*

### *Ocean Acidification*

Another climate change related phenomenon, ocean acidification, is being added to the list of conditions requiring the attention of CNMI's monitoring programs. Uptake of $CO_2$ by the ocean helps moderate the rising atmospheric concentrations, but associated changes in the oceanic carbonate chemistry lowers the pH along with the carbonate saturation state in oceanic surface waters; this process is referred to as ocean acidification. Coral reef growth depends on the saturation state of carbonate minerals in surface waters. A reduced carbonate saturation state makes it more difficult for marine calcifying organisms, such as corals, to form biogenic carbonate minerals (Orr et al., 2005).

### *Shoreline Change*

The University of Hawaii's (UH) Department of Geology and Geophysics was contracted to assess Managaha Island's shoreline stability and create a projected model of the shoreline in 10 years. Managaha is a small sand cay in Saipan Lagoon which has been showing a rapid rate of erosion from its northeast shore and accretion on the west since 1996 when wreckage was removed from the windward side of the key. Sea level rise would exacerbate the trend. The sand's dynamic shift has covered some coral habitat under sand, but the shift has also exposed new hardbottom habitats to potential colonization.

Scientists used aerial and satellite imagery, beach profiles and current models to complete the study in June 2007. The projected model indicates that the cay's infrastructure is not at risk. However, Shearwater bird habitat is in the path of the erosion. Based on the study's findings UH recommended that coastal managers observe the island for another two years, and if it has not settled into a dynamic equilibrium by that time, hire a coastal engineering firm to design and implement mitigation measures to stabilize the island. Proposed mitigation measures would include construction of groins or artificial reef, which may impact existing coral habitat.

A concurrent study of Saipan's western shore is underway, with quarterly beach profiles being taken from 14 sites around the Garapan district. Findings will be used for planners to test various shoreline management measures (e.g., submerged artificial reefs, beach nourishment, etc.) that may be used to protect infrastructure at risk in the face of sea level rise. Again, the mitigation measures proposed to maintain existing coastal structures may impact reef habitats.

## Diseases

### *Coral Diseases*

Coral diseases have received little attention in the CNMI until recently. Various types of coral disease have been observed affecting corals in the CNMI, but they have not been fully characterized. Pending the completion of data analysis, the coral disease survey conducted during the 2007 Mariana Reef Assessment and Monitoring Program (MARAMP) cruise will provide an initial overview of coral disease for the entire archipelago.

Only recently has a standardized method for naming coral diseases become available (Work and Aeby, 2006), so it is difficult to compare disease types observed in Saipan to elsewhere in the Pacific. Certainly, some of the conditions seen in Saipan are commonly found on other Pacific reefs, including pink/purple blemishes, rings and indentations on massive *Porites* and growth anomalies on *Acropora*, *Isopora* and massive *Porites* species. Localized bleaching, focal or multifocal tissue loss, tissue necrosis and discolorations were also frequently observed. These diseases have affected massive, encrusting and branching species in the genera *Acropora*, *Astreopora*, *Favia*, *Goniastrea*, *Leptastrea*, *Montipora*, *Pocillopora*, *Porites*, *Psammacora* and *Stylophora (Figure 14.4)*.

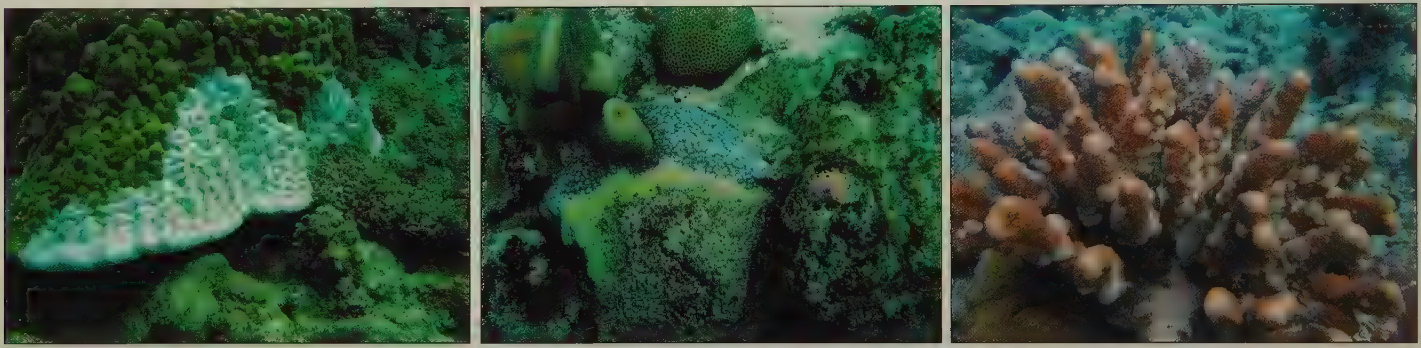


*Figure 14.4. Examples of coral diseases. From left to right: a massive* Porites *with partial bleaching; submassive* Astreopora *with a band of necrotic tissue; and branching* Isopora *with growth anomalies. Photos: D. Gochfeld.*

Overall prevalence of coral disease increased from 2002 to 2005, and in 2005, diseases were found to be more abundant at sites with high levels of diver activity (e.g., dive entry sites at Obyan and Lau Lau Beaches; (Gochfeld, unpub. data). However, diseases were also observed at offshore sites (e.g., Coral Ocean Point, Outside Grand Hotel and Akino Reef) and at those with high water motion (Wing Beach). The incidence and prevalence of coral diseases in Saipan, as well as their etiology and ecology, warrant further investigation.

### *Other Coral Reef Diseases*

Both coralline lethal orange disease and target syndrome affect coralline algae in the CNMI. A black fungus also affecting coralline algae is reported from Saipan, but has yet to be confirmed histologically. Lesions have been observed on the sea cucumber *Holothuria atra* in Saipan Lagoon. The effects on the animals range from burn-like patches to disintegration of the body wall. The CNMI marine monitoring team is investigating the prevalence of these lesions and possible environmental correlates.

## Tropical Storms

The CNMI archipelago is situated in a highly active region of the western Pacific for cyclones and tropical storms sometimes referred to as "Typhoon Alley". An average of three tropical cyclones per year have passed within 300 nautical miles of Saipan since 1970 (Landers, 2004). CNMI storms rapidly develop, and typically, but not exclusively, occur in the more humid summer months (Figure 14.5). Tropical storms in the CNMI region generally propagate from the east-southeast direction with large (2-6 m) short period (3-12 seconds) and long period (11-25 seconds) storm-wind swells propagating from the storm itself and from direction of their origin (typically a distant storm in the high southern or northern latitudes), respectively. Large offshore wave heights associated with high storm driven winds can cause physical damage to the reef, and storm surge and setup from offshore wave inundation can increase mean shoreline water levels (and thus local sea level) by over 40% of the offshore significant wave height (Vetter, 2007). Large influxes of fresh water, including anthropogenic inputs, produced by the heavy rainfall and land runoff from storm conditions can cause a large volume influx of cold, fresh (and often polluted or nutrient enriched) water to the coral reef environment, with prolonged exposure to these conditions resulting in detrimental affects to the coral reef ecosystem (Jokiel, 1993). Problems also arise with associated erosion, turbidity at drainages and seasonal river mouths, debris accumulation and accidental pollutant spills. However, to a certain degree, the coral reef ecosystems in the CNMI have evolved under these annual storm conditions and may benefit from such annual forcing (Becerro, 2006).

## Coastal Development and Runoff

Coastal development is managed through the coordinated efforts of the Coastal Resources Management (CRM) Office and CRM board member agencies, with the Department of Environmental Quality (DEQ) taking a leading role in managing earth moving and erosion control and water quality concerns. The declining rates of visitor arrivals and a receding economy have stalled several major proposed development projects. However, much of the existing development was created when weaker protective measures existed in local resource management regulations, resulting in many of today's focal problems. Runoff issues are dealt with in greater detail as coastal and nonpoint source pollution below.

## Coastal Pollution

The health and economic well being of the people of the CNMI depends on good water quality for fishing, recreation, and tourism. Healthy coral reefs require clean water with tested parameters remaining within a narrow range. Given that much of the existing development threatens our nearshore waters, maintaining and improving water quality in the CNMI is a challenge. Both point and nonpoint source pollution are responsible for lowering the quality of the CNMI's surface and ground waters. However nonpoint source pollution (NPS) is a greater source of impairment throughout the CNMI, specifically in the form of failing sewer collection systems, reverse osmosis discharges, urban runoff, sedimentation from unpaved roads and lack of proper erosion control best management practices during road and other construction activities.

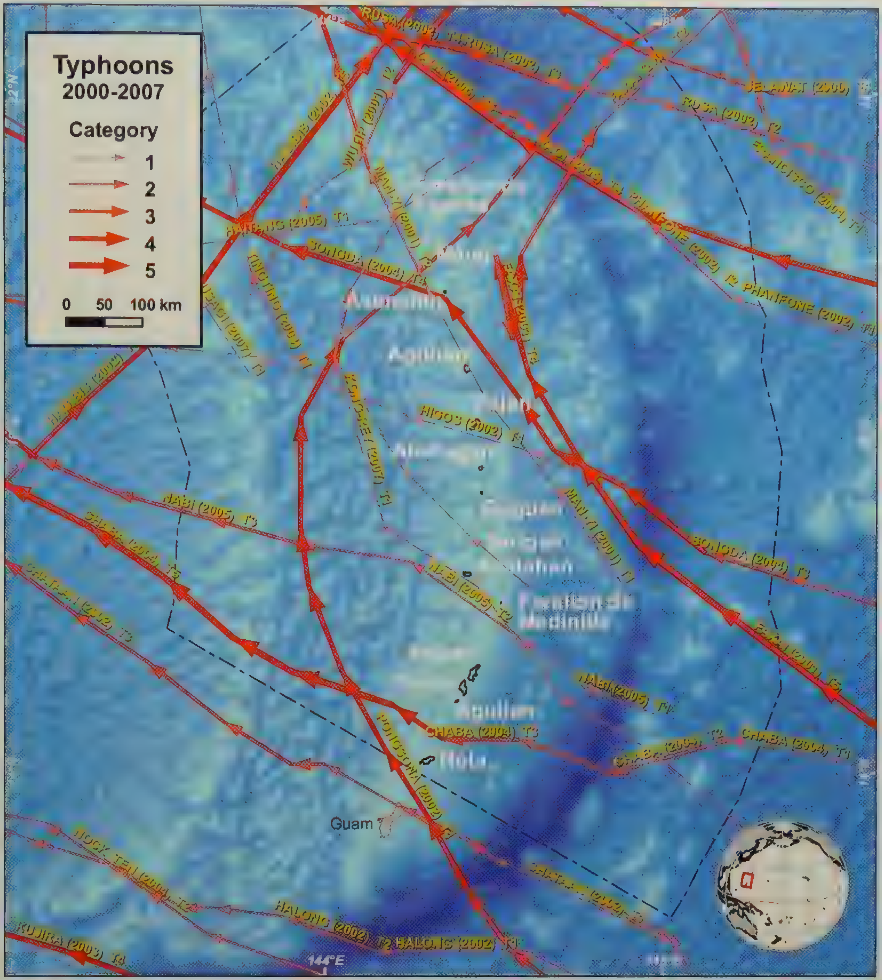


*Figure 14.5. The path, intensity and names (when known) of typhoons passing near the CNMI from 2000-2007. Many Pacific typhoons are not named or the names are not recorded in the typhoon database. Map: K: Buja. Source: http://weather.unisys.com/hurricane/.*

### *Nonpoint Source (NPS) Pollution*

NPS pollution remains one of the primary localized threats to coral reefs in the CNMI. In fact, one focus of the CNMI Marine Monitoring Team (MMT) is identifying reefs that are impaired by NPS pollution and prioritizing the limited funding allocated towards mitigation. Since 2000, MMT data demonstrate a steady declining trend in resiliency at "impaired" (defined by territory 305b water quality reports) localities. Specifically, decreases in species richness and recruit abundance, coupled with an increased dominance by one or a few corals, is becoming apparent at sites influenced by watershed pollution, while no such trend exists at other monitored sites (Figure 14.6).

The CRM Office and DEQ have long partnered to monitor and manage NPS in the CNMI. The CRM NPS program was funded by the federal 310 NPS Pollution control program, which was eliminated in fiscal year 2007. This has resulted in the elimination of what was once a highly effective program in the local CRM and has indefinitely stalled several major architectural and engineering best management practices (BMP) from being constructed as well as the implementation of proven local initiatives to combat NPS pollution.

### *Point Source Pollution*

The Commonwealth Utility Corporation is in the process of upgrading sewage transfer and treatment infrastructure. A sewer line replacement project completed in 2006 has eliminated chronic lagoonside sewer line overflows in San Antonio, Saipan. A long overdue repair project at Agingan Point Sewage Treatment Plant on Saipan will relocate the outfall, which presently empties directly into the sea at the waterline. Directional drilling will relocate the outfall to a location approximately 244 m (800 ft) from shore and at a depth of 30 m (100 ft). While the secondary treatment process will not be upgraded to tertiary, the relocation of the outfall will improve nearshore water quality by releasing the treated effluent into ocean currents that will carry it into the open ocean and away from coastal areas.

In 2005, nearly all major hotels were illegally releasing hypersaline and nutrient enriched wastewater from reverse osmosis water purification systems into drainages that directly affected water quality in the Saipan Lagoon. Action by the U.S. Environmental Protection Agency (EPA) resulted in a rapid mitigation effort, and the majority of these systems are now discharging into deep injection wells. While this action has provided short-term improvement in nearshore water quality, it is uncertain what the long-term effects of wastewater injection will be.

## Tourism and Recreation

CRM regulates commercial marine recreational sports through its permitting process. Commercial use of a beach front for filming, or the marine environment for SCUBA diving, banana boats, parasailing, submarine tours, commercial and personal jet ski usage, and other motorized marine sports activities must receive a permit from CRM (Table 14.1). The CRM has further designated jet ski exclusion zones near hotels, shallow reefs and seagrass habitat. Recent discovery of seagrass bed propeller scars associated with marine sports concessions has prompted an investigation of the ecological impact of these activities in Saipan Lagoon.

At the same time hotel operators have been seeking permission to remove seagrass beds from their designated swim zones. To date, no operators have applied for a CRM permit, as moving swim zones to areas without seagrass is easier than meeting the requirements of Section 7 of the Endangered Species Act or applying for a U.S. Army Corps Section 401 permit. CRM continues to give presentations to schools, the public and the Chamber of Commerce on the importance of preserving seagrass beds as a nutrient sink for NPS pollution, and as a fisheries nursery and habitat.

## Fishing

While the status of most concerns mentioned in previous reports has not changed, recent enforcement of a ban on gill, drag and surround nets appears to be having positive effects on fisheries resources within the Saipan Lagoon. Cast nets (talaya) are still legal with a permit and exemptions are issued for annual celebrations (fiestas) honoring villages' patron saints. On the whole, however, large nets are no longer used in CNMI, and conversations with local cast net, hook and line, and spear fishermen indicate an increasing abundance and size of food fishes in the lagoon (Starmer, pers. obs.). While there is presently no quantitative assessment of the effect of this net ban, DFW is planning to repeat surveys completed in the Southern Lagoon in 2008.

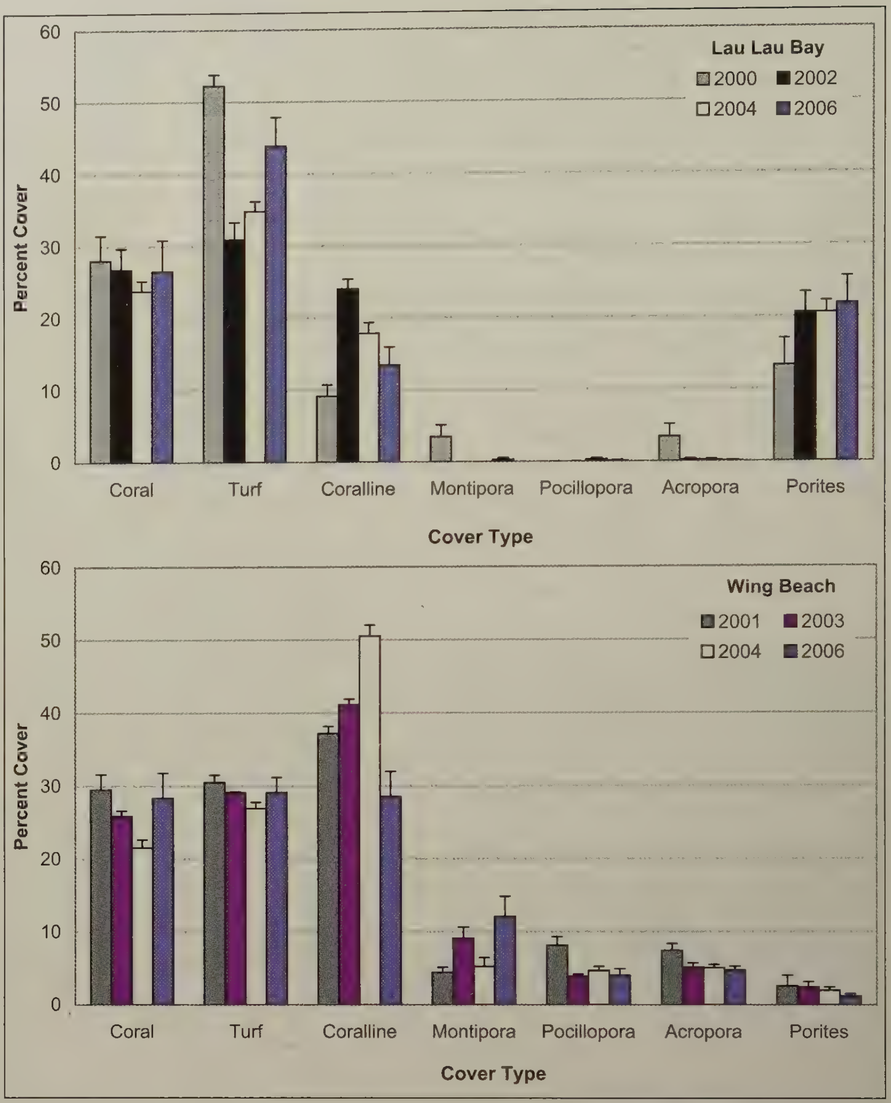


*Figure 14.6. Change in percent cover of corals and dominant benthos at an "impaired" site at Lau Lau Bay, Saipan (top) and a "healthy" site at Wing Beach, Saipan (bottom). Notably, change in total coral cover does not differ, however* Montipora, Pocillopora, *and* Acropora *corals are being replaced by* Porites *at the "impaired" site (top), yielding a decreased diversity as a result of watershed-based pollution. Source: CNMI MMT.*

*Table 14.1. Changes in permitted marine sports activities in CNMI between 2005 and 2007. Source: CNMI CRM.*

| | SAIPAN | | TINIAN | | ROTA | | TOTAL | |
|---|---|---|---|---|---|---|---|---|
| | 2005 | 2007 | 2005 | 2007 | 2005 | 2007 | 2005 | 2007 |
| Jet Ski | 12 | 12 | 2 | 1 | | | 14 | 13 |
| Banana Boat | 17 | 20 | 2 | 4 | | | 19 | 24 |
| Parasailing | 10 | 8 | 1 | 2 | | | 11 | 10 |
| Sea/Aqua Walker | 4 | 3 | | | | | 4 | 3 |
| Scuba | 27 | 51 | 2 | 1 | 1 | 3 | 29 | 55 |
| Snorkel Tours | 2 | 19 | | | | | 2 | 19 |
| Waterski/Wakeboard | | 8 | | | | | | 8 |
| Non- Motorized Marine Sports | 10 | 12 | | | | | 10 | 12 |

## Trade in Coral and Live Reef Species

This activity is prohibited by local law and is not recognized as a threat in this jurisdiction.

## Ships, Boats and Groundings

Recreational anchoring remains a concern, primarily at dive sites that are the focus of marine sports activities. Thirty-six existing moorings in the CNMI have been installed and maintained primarily by the private sector, including Dive Rota around Rota Island and Northern Marianas Dive Operators Association around Saipan and Tinian. However, the number of moorings is recognized to be insufficient, especially at popular diving locations. Further, anchoring is banned within local MPA's, which are among those sites commonly visited by recreational dive charters. To address the issue, NOAA Fisheries grant funding is being used to install at least fifteen additional moorings over a three-year period (2007-2009) to support the protection of reef fish habitat (http://www.cnmicoralreef.net/mooring/mooring.htm).

The current anchoring practices of prepositioned military vessels in coral reef habitat west of Saipan remains a concern as well. Benthic habitat and bathymetric surveys by PIFSC-CRED found high coral cover at sites proposed for additional anchorages.

In June 2003 NOAA's Office of Response and Restoration (NOAA ORR) conducted surveys of 42 abandoned vessels in the CNMI. Of these, 19 vessels were listed as navigational threats and 11 vessels were considered high priority vessels for removal by the CNMI Coral Reef Task Force (CRTF; Table 14.2).

*Table 14.2. CNMI's high priority vessels for removal. Source: CNMI CRM.*

| VESSEL | SPECS | WHERE | THREATS | STATUS |
|---|---|---|---|---|
| **SAIPAN** | | | | |
| *Mwaalil Saat* (Cost $3,500,000) | 93 ft steel trawler | Afloat outside harbor adjacent to the then Puerto Rico dump. | Potential pollution spill, navigational and public health risk | Removed and scrapped September 2004 |
| *Samala* (Phase I Cost $56,450) | 110 ft wood cabin cruiser | Grounded outside of Outer Cove Marina in shallow water | As it disintegrates, debris field moves and causes damage to corals and seagrass beds | Majority of debris removed by Sept 2005. Phase II estimated cost $20,000 |
| *Nago No. 15* (Cost $49,100) | 53 ft fiberglass longliner | Grounded in 3-5 ft of water in Saipan's lagoon | Movement during storms has scoured seagrass beds | Removed and scrapped February 2006 |
| *Charito* (In-kind contribution) | 97 ft steel longliner | Grounded in 5 ft of water front of a boat ramp in the lower base industrial area | Eyesore, potential threat to other boats in a storm, and public hazard | Scheduled for Spring 2007 |
| **ROTA** | | | | |
| *#62 Nam Sung* (Cost $6,000 and in-kind contribution) | 63 ft Steel fishing boat | Grounded on Sasanlago-Tatqua Beach | Extensive debris field damages corals and public health hazard | Scheduled for Spring 2007 |
| *TT Gov't 1/1830* | 106 ft steel M-Boat | Grounded in West Harbor | Public Health hazard | |
| *TT Gov't 2/1831* | 106 ft steel M-Boat | Grounded in West Harbor | Public Health hazard | |
| *Rota Queen* | 65 ft Tug boat | Grounded in West Harbor | Public Health hazard | |
| **TINIAN** | | | | |
| *Lian Gi* | 129 ft Steel freighter | Docked in Tinian Harbor | Will eventually sink and impact reef, poses a Public Health hazard | Cleaned and scuttled in Fall 2003 |
| *Sun Long No. 8* | 325 ft Steel freighter | Grounded in Tinian Harbor | Extensive debris field damages corals and public health hazard | |
| *Unk 2578-2579* | | Grounded Tinian Harbor next to dock | Public Health hazard | |

The CNMI CRTF began a Derelict and Abandoned Vessel Program in 2003 to initiate the removal of high priority vessels. Between 2004-2007, over $3.6 million of funding from the CNMI Coral Reef Initiative Management grant, U.S. Congress, FEMA Hazard Mitigation Sub-grant, U.S. Coast Guard (USCG) Oil Spill Liability Response Fund, NOAA Marine Debris Removal Program, and CNMI in kind and local funding have been targeted toward removal of five of the listed vessels. This figure does not include the $137,000 paid by the owner of the derelict vessel, *Lian Gi*, to scuttle her in 2003.

Three high priority vessels have been removed from Saipan's shores since 2004, including: the *Mwaalil Saat* (scuttled 2004- $3,500,000), *Samala* (scrapped 2005 - $56,450), and the *Nago No. 15* (scrapped 2006 - $49,100). Discussions are now underway with the USCG and U.S. Navy to scuttle the *Charito*, which grounded in Saipan Lagoon as part of ongoing military exercises. The CRM Office on Rota is presently removing the #62 *Nam Sung* wreckage from Tatqua Beach.

The CRM Office, DEQ, the CNMI Attorney General's Office, and USCG in conjunction with the CNMI Department of Public Safety (DPS) Division of Boating Safety, are discussing ways to prevent vessels from grounding or from being abandoned by their owners. Solutions include creating derelict and abandoned vessel legislation and creating an emergency fund to allow for the removal of vessels at risk before they go aground or sink. Other possible solutions include expanding the DPS annual inspections to include vessel integrity as part of the boat safety inspection requirements, and requiring vessels owners who use moorings or slips to obtain insurance to cover possible removal and mitigation costs.

### Marine Debris

There has been no change in the overall status of this threat for the CNMI. Observations during exploratory dives by the CNMI MMT indicate that there is a smattering of vessel debris ranging from anchors to machinery components to unidentifiable metal scraps scattered along the west coast of Saipan from Tanapag Channel to Agingan Point and along Tinian from Unai Babui to the San Jose. Accumulations of metal debris, including unexploded ordinance that has been dumped from cliffs, can be found at Agingan and Naftan Points, Saipan and at Faibus Point (Dump Coke), Tinian. A PIFSC-CRED towed-diver survey at Tinian reported helicopter fragments and large tires at Faibus Point. Marine debris was not commonly encountered during PIFSC-CRED towed-diver surveys in the Marianas Archipelago. Infrequent sightings included isolated monofilament line (at Alamagan) or other types of fishing line (at Uracus and Tinian), miscellaneous rope or line (at Maug and Sarigan) and an anchor line (at Arakane).

### Aquatic Invasive Species

There has been no change in the overall status of this threat for the CNMI. A commercial attempt to introduce several non-native species of *Tridacna* from Palau failed after the clams died of unspecified causes.

### Security Training Activities

The status of concerns mentioned in previous reports has not changed. The U.S. military is currently proposing a build up of personnel in the neighboring U.S. Territory of Guam that may number in the tens of thousands. If this occurs, the CNMI will likely see an increasing frequency of training exercises in coming years.

### Offshore Oil and Gas Exploration

Offshore oil and gas exploration is not occurring nor has it been proposed for the CNMI.

## CORAL REEF ECOSYSTEMS—DATA-GATHERING ACTIVITIES AND RESOURCE CONDITION

Several local and federal coral monitoring and mapping programs have been collecting data to characterize, define trends, and approach causal relations between CNMI's coral reef assemblages and driving environmental variables (Table 14.3; Figure 14.7). Local efforts supported by the NOAA monitoring and EPA water quality monitoring grants provide for the most spatially and temporally encompassing characterization of the reefs systems in the southern, populated islands. These efforts are focused upon the Saipan Lagoon and nearshore coral reefs around Rota, Aguijan, Tinian and Saipan. The structure of the local monitoring program follows the above noted blueprint (characterization-trends-causal relations) and aims to translate scientific findings for management activities such as Local Action Strategies, EPA waterbody assessments and prioritizations and the Micronesia Challenge. CNMI's efforts have benefited through numerous collaborations with federal partners, notably from NOAA's Biogeography Branch, which has conducted habitat mapping and reef characterization activities and manages the National Coral Reef Ecosystem Monitoring Program grants. Collaboration with the NOAA PIFSC-CRED has provided an opportunity for CNMI's local marine monitoring team to participate in data collection efforts in the volcanic northern islands and other remote areas (Figure 14.7). Collaboration with PIFSC-CRED brings many otherwise unattainable resources to examine coral reef assemblages and gather water quality and environmental data throughout the CNMI.

*Table 14.3. Monitoring programs in the CNMI. Source: CNMI MMT.*

| PROGRAM | VARIABLES | LOCATIONS | DATES | FREQUENCY | AGENCY |
|---|---|---|---|---|---|
| Coral Reef Early Warning Buoy | Enhanced: temperature (1 m), conductivity (salinity), wind, atmospheric pressure, ultraviolet radiation, photosynthetically available radiation | Saipan | 2003-2006 | Continuous | PIFSC-CRED |
| Deepwater CTDs* | Conductivity, temperature, depth, dissolved oxygen, chlorophyll to depth of 500 m | All Islands | 2003-present | Continuous | PIFSC-CRED |
| MARAMP REA | Coral, Fish, Algal and Invertebrate abundance and diversity, benthic cover | All Islands | 2003-present | Biennial | PIFSC-CRED |
| Marine Monitoring Program | Benthic cover, Coral Community Structure, Benthic Biodiversity, Coral Recruitment, Fish Abundance | Saipan, Rota, Tinian, Agijuan | 2000-present | Annual | CRM DEQ |
| Nearshore Water Quality Monitoring | Coliform Bacteria, Nitrate, Phosphate, Temperature, Salinity, PH, dissolved oxygen | Saipan (and Managaha), Rota, Tinian | 1995-present | Biweekly | CRM DEQ Environmental Surveillance Laboratory |
| Sanctuary Program | Fish abundance and diversity, invetebrate abundance, rugosity | Saipan, Rota, Tinian | 2000-present | Annual | DFW |
| Sea Surface Temperature | Temperature at 0.5 m | Maug, Pagan, Rota | 2003-present | Continuous | PIFSC-CRED |
| Shallow-water CTDs* | Temperature, conductivity, turbidity | All Islands | 2003-present | Continuous | PIFSC-CRED |
| Subsurface Temperature Recorders | Temperature between 0.5 and 30 m | All Islands | 1995-1996, 2001-present | Continuous | PIFSC-CRED, CNMI MMT |
| Water Samples | Chlorophyll, nitrate, nitrite, silicate, phosphate concurrent with deep and shallow-water CTDs* at selected depths | All Islands | 2003-present | Continuous | PIFSC-CRED |
| Wave and Tide Recorders | Wave and Tidal Height | Supply Reef and Zelandia Bank | 2003-present | Continuous | PIFSC-CRED |
| Ocean Data Platform | Temperature, conductivity (salinity), spectral waves, current profiles | Santa Rosa Reef | 2003-present | Continuous | PIFSC-CRED |

*CTD stands for a sensor that measures conductivity, temperature and depth.

Within the Mariana Archipelago the most notable broad-scale reef-community zonation pattern exists between the northern volcanically active islands and the southern raised limestone islands. Examinations of 40 fringing reefs throughout the northern islands found that while coral diversity and colony surface area are significantly lower on the northern islands than the southern (mean of 62 species per site and 206 cm$^2$, mean of 82 species, 312 cm$^2$, respectively (Houk and Starmer, unpub. data), population density is similar (mean of 144 and 139 colonies per site, respectively). This suggests that recruitment is not limiting, rather that harsh environmental conditions select against species settlement and growth (Randall, 1985; Houk, 2006). The failure of much of the coastline around the northern islands to form into fringing reefs is attributed to: 1) unfavorable bathymetry, 2) a lack of favorable substrate upon which corals can settle and grow, 3) high exposure to wave energy, 4) the re-suspension of volcanic ash, and 5) volcanic eruptions. In the southern, raised limestone islands local efforts have provided enhanced characterizations of the coral reefs in areas where reef growth has not been uniform throughout the late Holocene. In some places, spur-and-groove reef types exist, while others are devoid of deposition entirely.

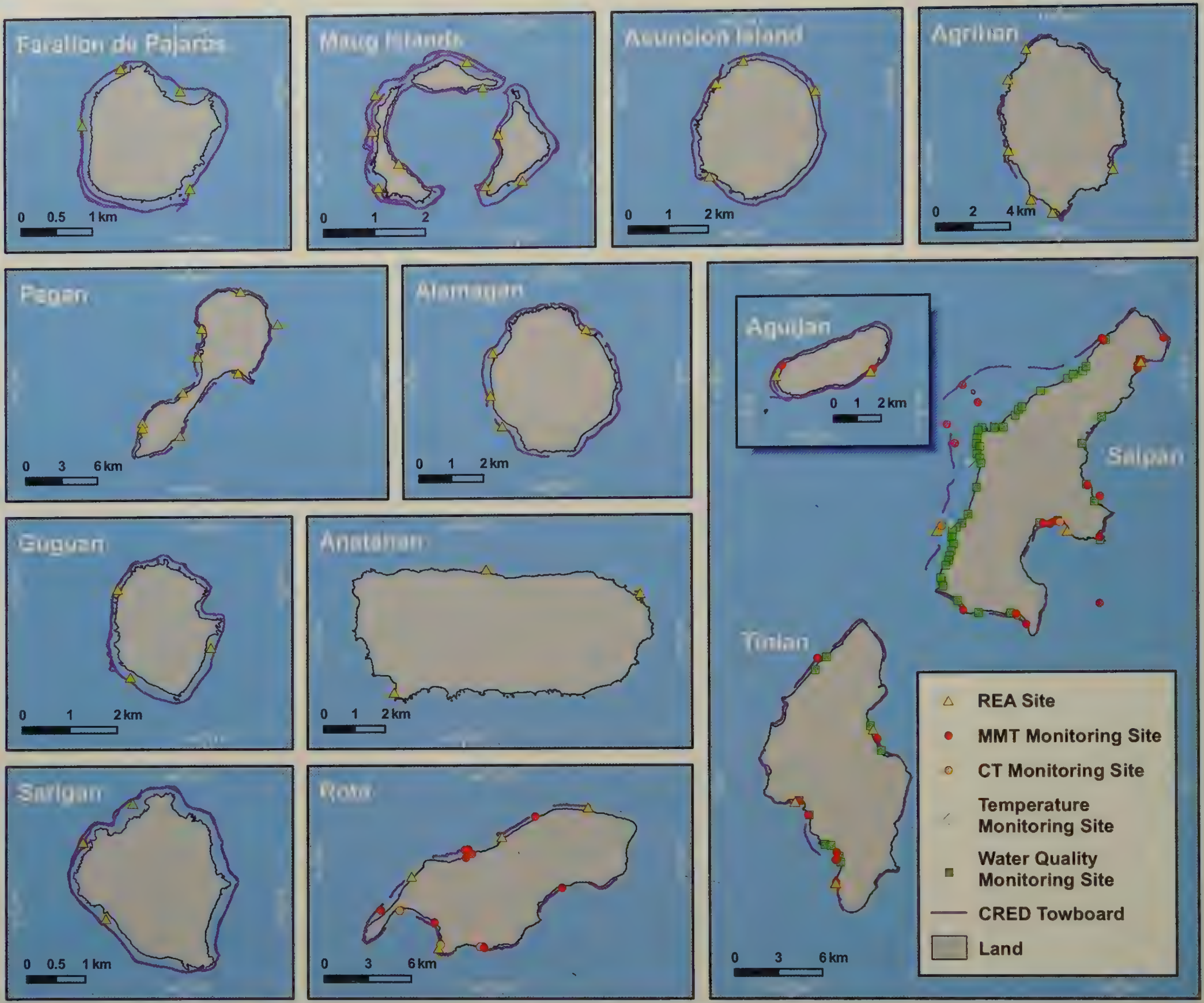

Farallon de Pajaros
0 0.5 1 km
Maug Islands
0 1 2
Asuncion Island
0 1 2 km
Agrihan
0 2 4 km
Pagan
0 3 6 km
Alamagan
0 1 2 km
Aguijan
0 1 2 km
Saipan
Guguan
0 1 2 km
Anatahan
0 1 2 km
Tinian
0 3 6 km
Sarigan
0 0.5 1 km
Rota
0 3 6 km
△ REA Site
● MMT Monitoring Site
● CT Monitoring Site
Temperature Monitoring Site
■ Water Quality Monitoring Site
CRED Towboard
Land

*Figure 14.7. Monitoring locations sampled throughout the CNMI. Map: K. Buja.*

Houk and van Woesik (2008) identified four distinct geomorphological settings that hold significantly different modern coral assemblages: 1) Holocene "spur and groove", 2) Rota Holocene "slope", 3) unconsolidated Holocene, and 4) Pleistocene. By developing this understanding of overarching environmental constraints to coral reef community development, monitoring efforts are better able to distinguish anthropogenic from environmental changes in the marine environment. Building from these characterizations monitoring efforts are now moving into detecting trends that improve our understanding of cause. A summary of current progress and future directions are presented below.

## WATER QUALITY AND OCEANOGRAPHIC CONDITIONS

As with reefs globally, the health, functioning and biogeography of CNMI's coral reef ecosystems are influenced by the regional oceanographic conditions, such as waves, temperature, salinity, turbidity, nutrients, and other measures of water quality. As these conditions change, so do the physical condition, distribution, abundance, and species diversity of each reef community. NOAA PIFSC-CRED efforts have just begun to characterize oceanographic conditions in the CNMI, and future data analyses will provide more detailed insight.

Local water quality monitoring efforts are focused upon the southern islands. Of the 83 locations that are monitored for water quality by the DEQ Environmental Surveillance Lab, 37.3% were classified as "impaired" due to excess nutrient and bacteria levels in 2006 (Table 14.4; Houk, 2006). Unsurprisingly, most microbiological violations were recorded at beaches near storm water discharges (Figure 14.8), especially during rain events (Figure 14.8). Many of these beaches are associated with the Saipan Lagoon, representing CNMI's most developed coastline, however, impaired waters exist on all islands except Managaha. In total, 42% of Saipan's beach shoreline was classified as "impaired", while only 28.2% of Tinian's and 8.7% of Rota's beach shoreline were similarly classified.

The dynamic nature of water quality data makes it very difficult to properly assess an area without spatially comprehensive and frequent sampling. An alternative approach towards understanding water quality is to examine the biological communities that are bathed by the waterbody in question. In tropical marine waters, these communities change in response to nutrients, sediment loads, turbidity, and other parameters (Valiela, 1995; Fabricius, 2005; Houk et al., 2005). Building upon habitat maps that characterize the Saipan Lagoon, significant relationships have been reported between the extent and integrity of seagrass beds and watershed size and development (Houk and van Woesik, 2008). The two ubiquitous seagrass-dominated habitats, *Enhalus acoroides* and *Halodule uninervis*, responded differently to proxies of watershed pollution. Habitats dominated by the former show expansion with increasing watershed development, while high proxies to pollution were related to increased macroalge growth inside the *Halodule* beds, which shade out seagrass and indirectly decrease its abundance. Current and future efforts will continue to examine causal relations by monitoring permanently marked seagrass beds associated with watersheds of varying size and level of development. These studies aim to identify how change occurs and the ecological indicators of negative change.

*Table 14.4. Statistics associated with the CNMI Division of Environmental Quality's beach monitoring results from 2006. Source: Houk, 2006.*

| ISLAND | # BEACH MONITORING SITES | % WITH IMPAIRED WATER | % BEACH COASTLINE WITH IMPAIRED WATERS |
|---|---|---|---|
| Saipan | 50 | 48.2 | 42 |
| Managaha | 11 | 0 | 0 |
| Tinian | 10 | 40.1 | 28.2 |
| Rota | 12 | 25 | 8.7 |
| **Overall** | **83** | **37.3** | **28.8** |

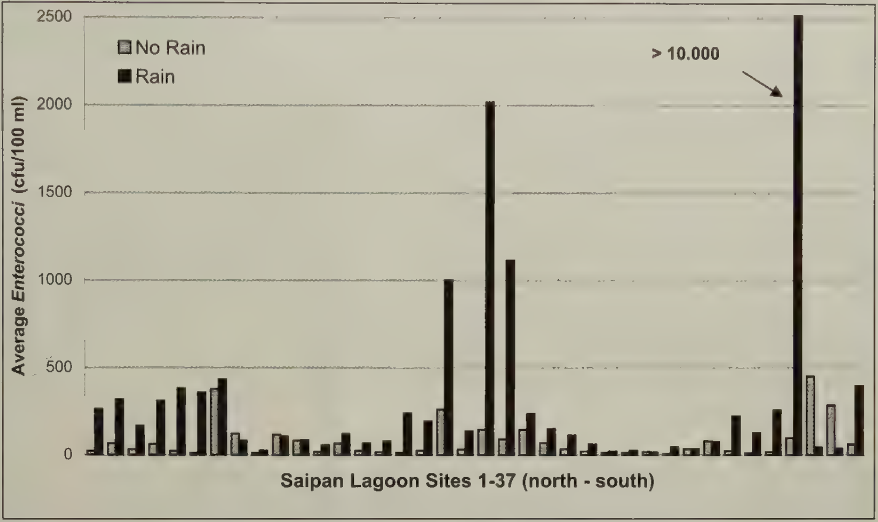


*Figure 14.8. Average* Enterococci *bacteria levels for 2006 at monitoring stations on the west coast of Saipan Island. Source: CNMI DEQ.*

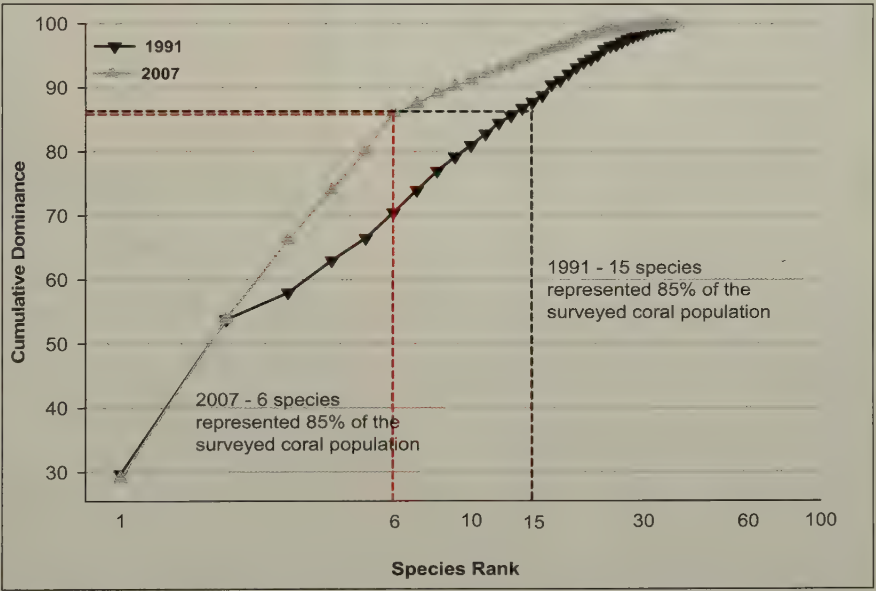


*Figure 14.9. Coral species accumulation curves for reef-slope assemblages in Lau Lau Bay from 1991 and 2007. Source: CNMI DEQ.*

Building upon geomorphological and environmental characterizations of CNMI's nearshore reefs, Houk and van Woesik (2008) found significant relationships between watershed development, human population density, and several ecological measures of coral reef communities that were most responsive to proxies of pollution. Coral species richness and abundance of recruits were the most sensitive indicators to land based pollution, while not being significantly altered by large-scale natural disturbances. In support, monitoring trends show decreased coral species richness in Lau Lau Bay where water quality has been declining due to land-based pollution (Figure 14.9). Ecological measures are currently being used as indicators to evaluate the "status" of nearshore reefs. A major informational gap is the current understanding of the fate and magnitude of watershed discharge to the marine environment. The raised, karst nature of the populated Mariana Islands makes visual estimations of the location and quantity of freshwater discharge (a proxy to pollution) insufficient. CNMI's goals are to create detailed maps of nearshore marine water quality using continuously-recording, water quality testing instruments integrated with positional data (global positioning system data), that together will yield Geographic Information System (GIS) layers for interpretive and modeling purposes (Figure 14.10). These results would estimate the spatial boundaries of watershed influence, and compliment the existing long-term biological monitoring that examines patterns, causes and processes that alter our coral reef ecosystem.

While DEQ's attended monitoring continues to provide a robust data set on populated islands, collecting water quality data throughout the entire CNMI is a daunting task that is gradually being met through the application of *in situ* data logging instrumentation (Table 14.3). The PIFSC-CRED program has enhanced coverage of data logging and satellite-linked water quality instrumentation since 2003 (Figure 14.11; Maug and Pagan, PIFSC-CRED), budget constraints already have impacted this program, as evidenced by the removal of a CREWS buoy in 2007.

However, local efforts, supported primarily through the Territorial Monitoring Grant Program, have been gradually expanding. The majority of monitoring stations presently measure temperature and salinity with basic loggers, but multi-parameter data sondes have recently been procured to characterize other parameters of CNMI's nearshore water quality (Figure 14.12). Further, efforts are underway to bring the NOAA ICON/CREWS program to Saipan in 2008, with direct support from CRM and the Territorial Monitoring Grant.

Most of the water quality data are analyzed on a site-specific basis, with future efforts aiming to produce spatial connections. For instance, unattended water quality instruments are now being used to characterize the effects of a newly established breakwater on SST in Rota's west harbor. The breakwall has isolated one portion of the lagoon and the alteration of water flow has increased temperature variability and appears to be hampering ecological recovery of benthic assemblages.

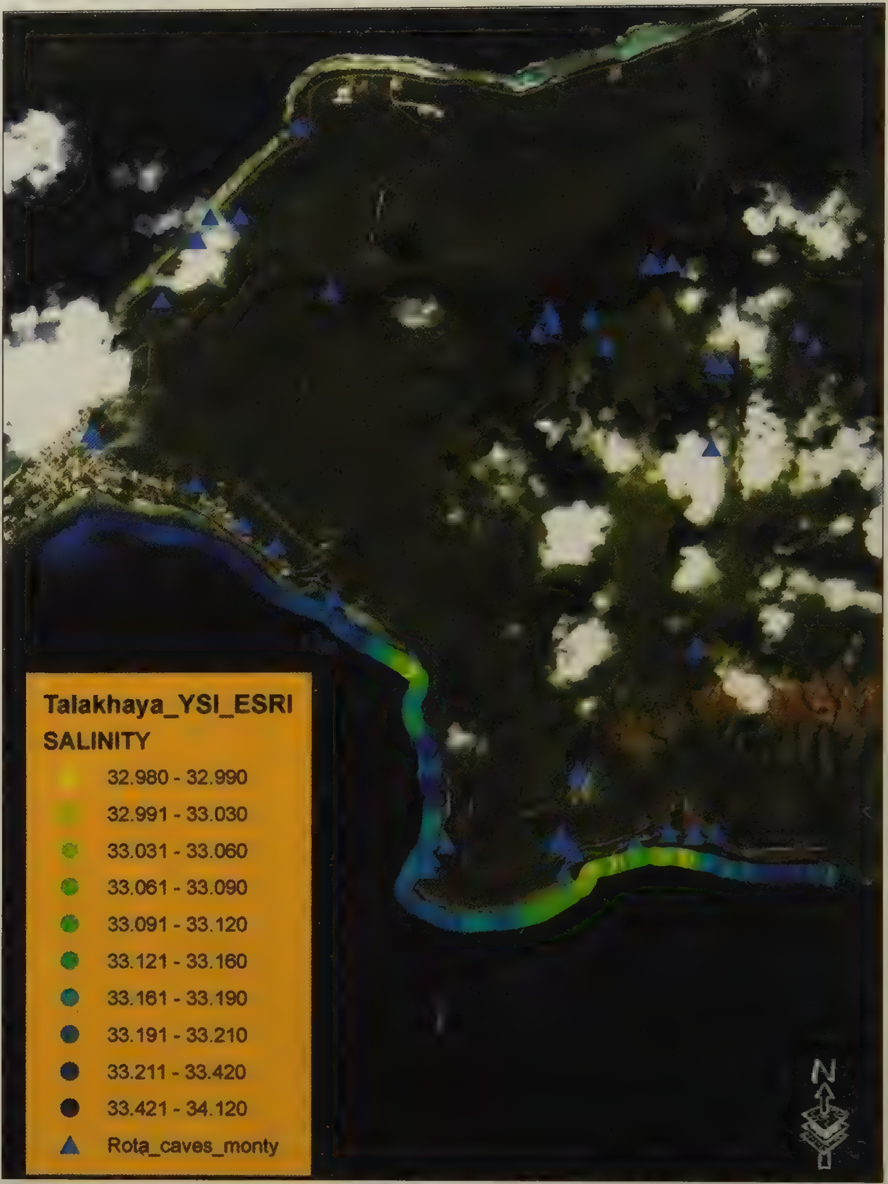


Figure 14.10. The coast of southern Rota showing variation in salinity at 1 m depth in relation to cave features. Source: CNMI MMT and Monty Keel.

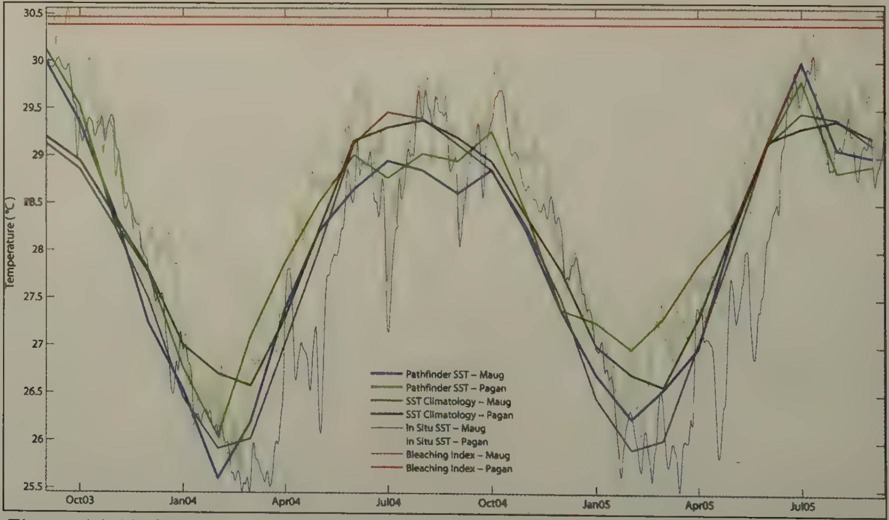


Figure 14.11. Satellite and in situ temperatures at Maug and Pagan. Throughout the three year time series, satellite derived SST shows mostly seasonal oscillations. Coral Reef Watch bleaching threshold of maximum monthly mean SST plus 1°C are included for reference. Source: PIFSC-CRED,unpub. data.

## BENTHIC HABITATS

As stated earlier, the most extensive habitat mapping products have been created by the NOAA (2005). These products provide basic geological and ecological characteristics for the entire CNMI. Building from these products, the Saipan Lagoon was mapped in greater ecological detail using ground-based techniques (Houk and van Woesik, 2008). Changes over the past 50 years were assessed by comparing temporary habitat occurrences with those evident in the late 1940s (Cloud, 1959). There have been declines in the occurrences and extent of coral habitats (particularly staghorn *Acropora*), and increases in seagrass and algae habitats that were correlated with watershed characteristics (discussed above in the water quality section). Anomalous increases in SSTs evident in 2000 and 2006 caused high mortality (up to 50%) within back reef coral assemblages. It appears that nearshore seagrass habitats are most impacted by land-based pollution, while offshore back reefs suffer greatest from natural disturbances. Expanding from these characterizations and preliminary trends, a Saipan Lagoon monitoring effort has been established to continue to document and understand change over time at 28 permanent locations.

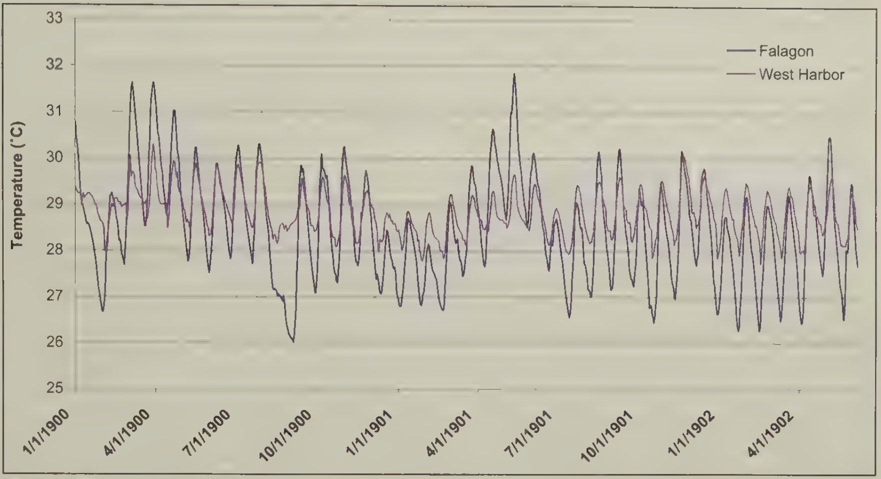


*Figure 14.12. Temperature variation on the lagoon side (Falagon) and harbor side of a constructed breakwater at West Harbor, Rota. Source: CNMI MMT.*

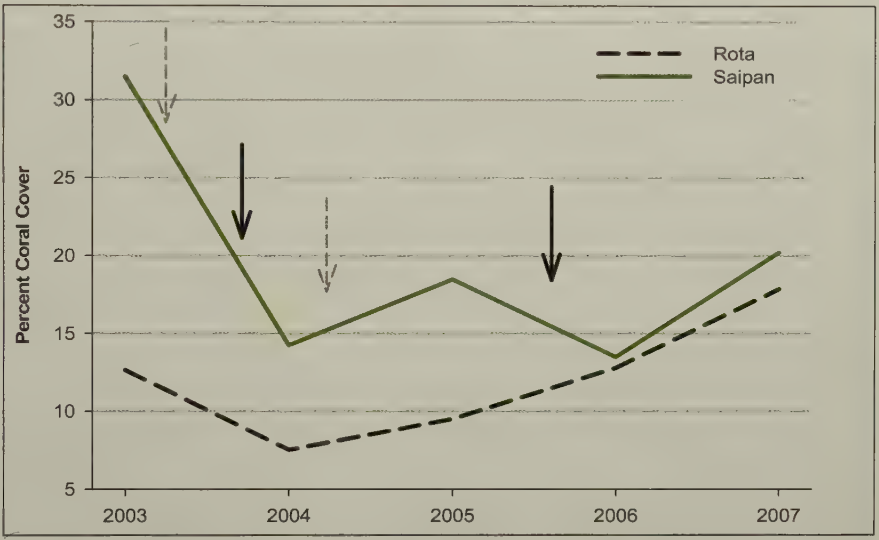


*Figure 14.13. Trends in coral abundance on Saipan and Rota. Dashed arrows indicate high coral-eating sea star populations. Solid arrows indicated climate-induced coral bleaching. Source: CNMI MMT.*

Described in the introductory section, the nearshore reefs assemblages can initially be characterized by their geological and environmental setting, and trends over the past six years are best understood by comparing similar reef types (e.g., stratification). The most influential disturbances that have occurred in the CNMI since monitoring by the MMT was initiated in 2000 were high populations of crown-of-thorns sea stars (COTS, *Acanthaster planci)* in 2003 and 2004 (Houk et al., 2007). Differences in resilience to these events have been noted at the island level (Figure 14.13), and among differing sites within islands (Figure 14.14). Declines in coral abundance were evident at most of the 30 monitoring locations during these disturbances; however, recovery of fast growing *Acropora* and *Pocillopora* corals varied, perhaps due to watershed and/or other oceanographic conditions. CNMI's marine monitoring program aims to analyze the rates of change in accordance with driving variables.

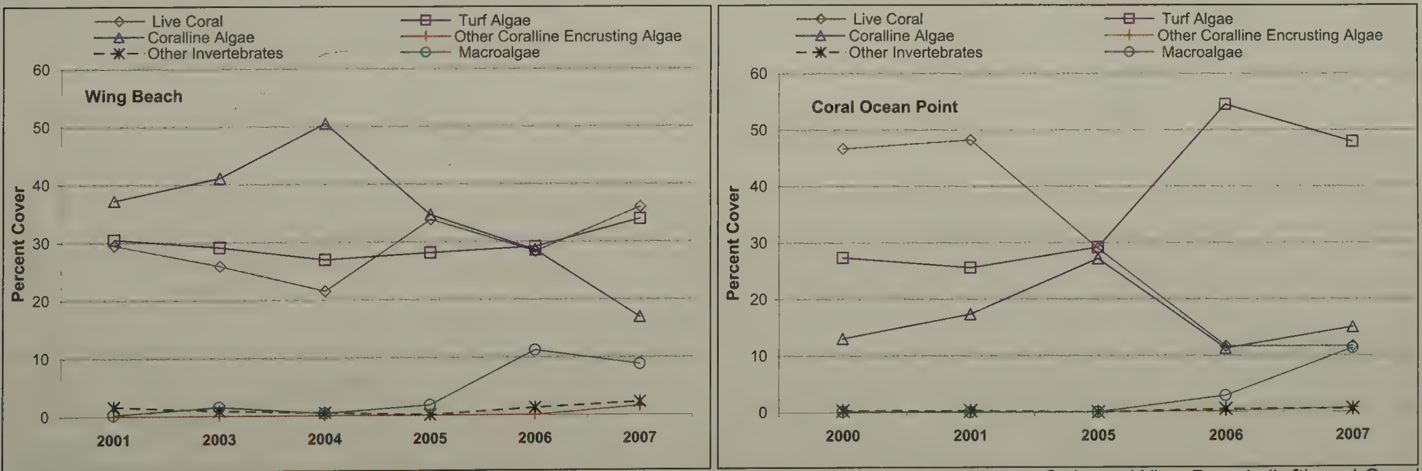


*Figure 14.14. Response to environmental perturbations at two local, long-term monitoring sites on Saipan: Wing Beach (left) and Coral Ocean Point (right). Source: CNMI MMT.*

Expanding on the existing MMT efforts, monitoring on the reef flats on Saipan, Tinian and Rota has recently begun. While most sites have only been visited a single time at present, two sites at Laulau Bay have been surveyed four times over two years (Figure 14.15). These surveys demonstrate a greater variability on reef flats than in fore reef environments, and indicate that the persistence of specific macroalgae may result from watershed-based pollution. Further information on local monitoring efforts is available online (http://www.cnmicoralreef.net/monitoring.htm).

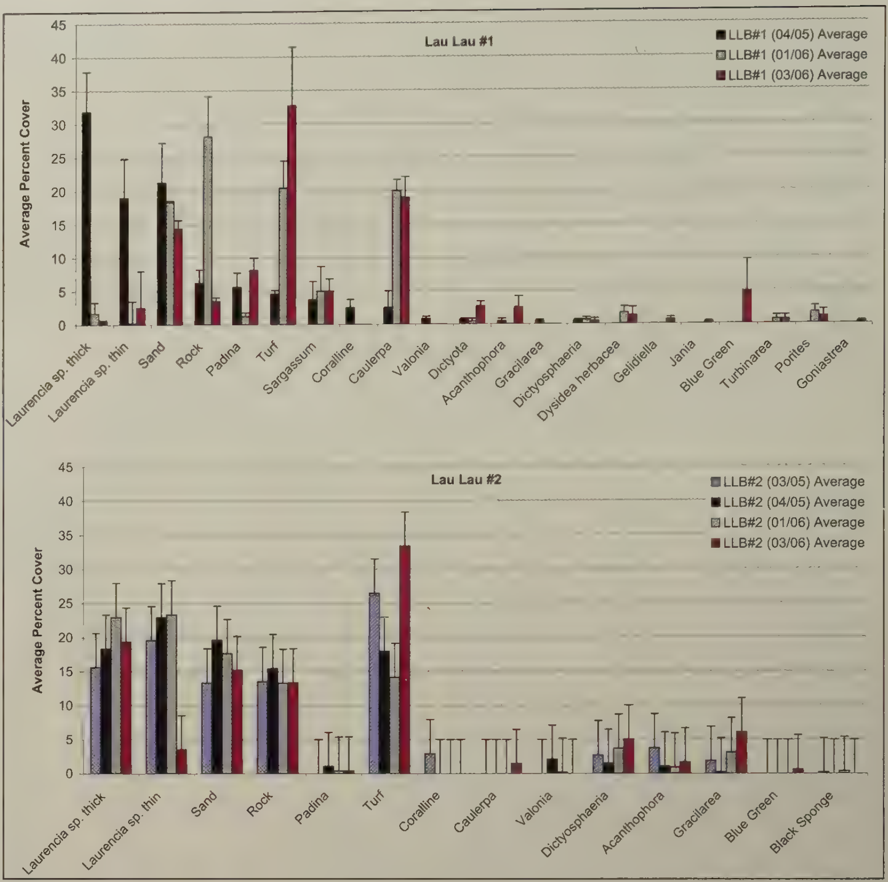


*Figure 14.15. Annual and seasonal differences in benthic cover at two reef flat sites on Saipan: (top) Lau Lau #1 and (bottom) Lau Lau #2. Source: CNMI MMT.*

In the remote northern islands, quantitative benthic surveys have been conducted on three occasions, led by NOAA's PIFSC-CRED and supported by several partner agencies in CNMI. The rapid ecological assessment (REA) data are currently being processed, however, initial analyses indicate that geology, water discharge patterns, and island size are the best predictors of modern coral assemblages. Unlike the southern islands, the relationship between the amount of vegetation in the watershed and the adjacent reef assemblage is weak, suggesting higher operating controls regulate coral reef populations.

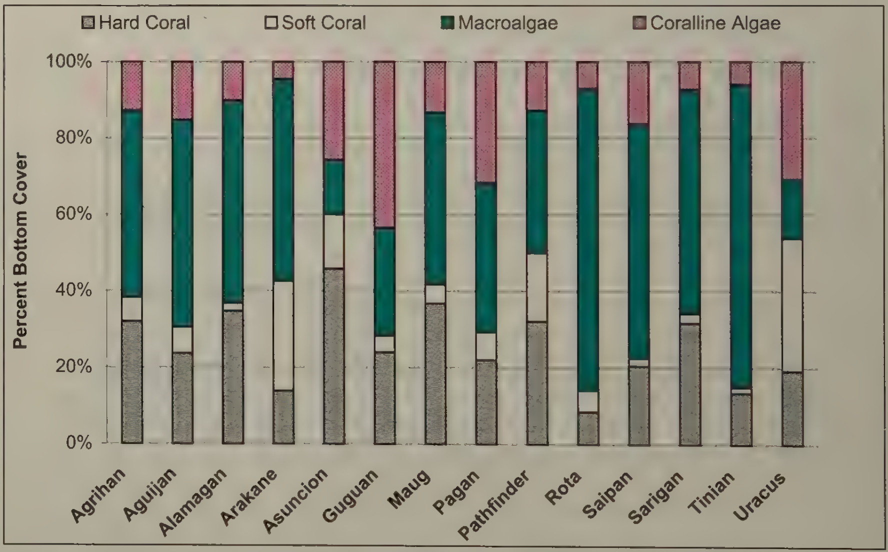


*Figure 14.16. Dominant benthic cover categories for CNMI, including selected offshore reefs at fore reef sites. Source PIFSC-CRED, unpub. data.*

MARAMP surveys also include a towed-diver approach that provides for broad coverage of island environments. A total of 110 towed-diver surveys were completed during the 2005 MARAMP, covering nearly 216 linear km of habitat and providing an initial overview of CNMI's benthic cover. These surveys revealed highly variable levels of coral and algal cover between islands (Figure 14.16). The highest overall hard coral cover was found at Pathfinder (average 25%, range 10.1–40%) and Maug (average 22%, range 0–75%). Maug had the highest coral cover for any single towed-diver survey conducted in CNMI, located along the western fore reef (average 55%, range 41.5–75%; Figure 14.16). Notable areas of soft coral cover were observed on Agrihan, where soft coral was dominant during several time segments along the western coast. Some of the vertical walls in the west had up to 90% coral cover. Arakane had the highest overall soft coral cover with an average of 25% and range of 1.1–62.5%. Algal cover was nearly as dominant as hard or soft coral cover on some islands: Rota had the highest overall macroalgae cover (average 56%, range 20.1–100%), followed by Tinian (average 53%, range 20.1–100%) and Arakane (average 46%, range 30.1– 75%). The highest overall coralline algae cover was recorded at Guguan (average 20%), followed by Pagan (average 13%).

The percent cover of hard coral with a loss of pigment from bleaching, predation, etc. is also assessed by towed-diver surveys as an indicator of coral stress. High levels of overall coral stress were recorded at Agrihan (average 5%, range 0.1–100%). The highest level of coral stress was located along the northeastern corner of Agrihan's fore reef (average 24%, range 0.1–100%; Figure 14.16). Pagan recorded the next highest overall coral stress level (average 3%, range 0–62.5%). The highest level of coral stress was located during a towed-diver survey along the northeast coast in the vicinity of Hira Rock and Baranka. In addition, at this site there were signs of COTS predation, along with higher numbers of COTS recorded during the survey than in any other area of Pagan, with 85 recorded within 50 minutes. Saipan had relatively low overall coral stress, with an average of 2% and a range of 0–40%. High levels of coral stress were recorded during towed-diver surveys completed between Puntan Obyan and Puntan Agingan in the south (average 13%, range 1.1–40%). Divers described certain sections of the survey as a "graveyard of *Pocillopora* on pavement". During the 50-minute survey, 99 COTS were counted, which represents the highest concentration (60 individuals) in any 60-second period surveyed in CNMI in 2005.

Data from 2003 and 2005 MARAMP surveys were used to examine spatial and temporal changes in relative abundance of macroalgae across the Mariana archipelago to test the usefulness of common and abundant algae as indicators of ecosystem condition (Tribollet and Vroom, 2007). Genus-level algal data showed abundance patterns that indicated distinct dichotomies between carbonate versus volcanic islands, populated versus unpopulated islands, and small versus large islands. The diversity of macroalgal genera was generally highest at the southern end of the archipelago, probably because of increased habitat heterogeneity around these larger islands. Relative abundance of macroalgae showed significant variability at the local scale (between sites within an island) and over time. The environmental heterogeneity in the CNMI provides for remarkable overall diversity. A joint effort between the PIFSC-CRED and the Bishop Museum is addressing algal biodiversity of the CNMI based on 2003 collections. Preliminary findings have tentatively identified 327 species, of which 110 are new records (Tsuda et al., unpub. data; Table 14.6).

*Table 14.6. Number of marine benthic algal species identified on each island, bank, shoal and remote reef in the CNMI (north to south) during the August and September 2003 cruise. Source: PIFSC-CRED; Tsuda et al., unpub. data.*

| ISLANDS, BANKS, SHOALS OR REEFS | NUMBER OF SPECIES | | | | |
|---|---|---|---|---|---|
| | Cyanophyta | Rhodophyta | Phaeophyta | Chlorophyta | Total |
| Uracas | 1 | 29 | 6 | 14 | 50 |
| Stingray Shoals | 1 | 6 | 3 | 1 | 11 |
| Supply Reef | 2 | 1 | 2 | 3 | 8 |
| Maug | 12 | 61 | 11 | 27 | 111 |
| Asuncion | 2 | 45 | 6 | 20 | 73 |
| Agrihan | 7 | 59 | 9 | 19 | 94 |
| Pagan | 11 | 91 | 11 | 37 | 150 |
| Alamagan | 6 | 51 | 8 | 20 | 85 |
| Guguan | 4 | 38 | 6 | 12 | 60 |
| Zealandica Bank | 2 | 9 | 1 | 6 | 18 |
| Sarigan | 8 | 31 | 5 | 12 | 56 |
| Anatahan | 2 | 28 | 2 | 10 | 42 |
| Pathfinder Bank | 3 | 14 | 2 | 6 | 25 |
| Arakane Bank | 2 | 8 | 4 | 7 | 21 |
| Saipan | 8 | 57 | 9 | 20 | 94 |
| Tinian | 7 | 41 | 9 | 17 | 74 |
| Aguijan | 8 | 31 | 6 | 23 | 68 |
| Tatsumi Reef | 1 | 3 | 0 | 1 | 5 |
| Rota | 9 | 82 | 12 | 39 | 142 |
| CNMI (number of species) | 23 | 192 | 21 | 91 | 327 |

### *Benthic Mapping*

In support of the U.S. Coral Reef Task Force's mission to "produce comprehensive digital maps of all shallow (<30 m) coral reef ecosystems in the United States and characterize priority moderate-depth reef systems by 2009," NOAA's CRCP has developed a comprehensive mapping program for the Pacific Islands region. As documented in Starmer et al. (2005), NOAA's Center for Coastal Monitoring and Assessment, Biogeography Branch (CCMA-BB) produced shallow water benthic habitat map products from IKONOS satellite imagery (Figure 14.17; http://ccma.nos.noaa.gov/ecosystems/coralreef/us_pac_mapping.html) and CRED conducted multibeam and optical validation mapping around Saipan and Tinian in 2003 (http://www.soest.hawaii.edu/pibhmc/pibhmc_cnmi.htm).

In addition to CRCP's benthic habitat mapping program, other major mapping and scientific initiatives are being sponsored by the U.S. in CNMI. NOAA's Ocean Exploration program conducted geologic and water chemistry surveys in the remote Northern Mariana chain in 2003 and 2006 as documented at http://oceanexplorer.noaa.gov/explorations/06fire/ and http://oceanexplorer.noaa.gov/explorations/03fire/. A 2007 NOAA-sponsored cruise aboard a U.S. Naval Oceanographic Office vessel the *U.S.N.S. Bowditch* mapped deeper waters of the western insular margin in order to better define the U.S. Exclusive Economic Zone.

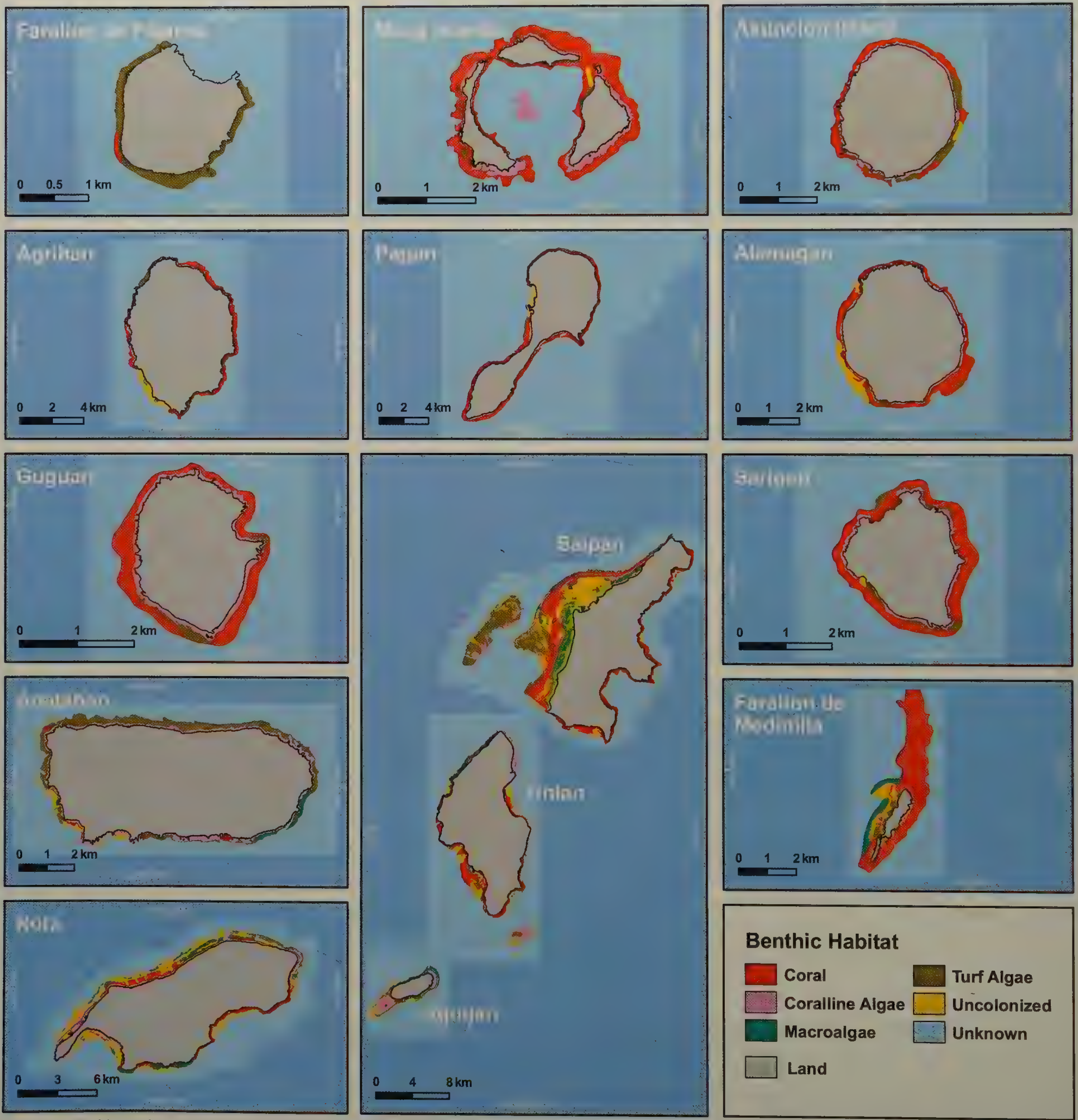

Farallon de Pajaros
0 0.5 1 km
Maug Islands
0 1 2 km
Asuncion Island
0 1 2 km
Agrihan
0 2 4 km
Pagan
0 2 4 km
Alamagan
0 1 2 km
Guguan
0 1 2 km
Saipan
Tinian
Aguijan
0 4 8 km
Sarigan
0 1 2 km
Anatahan
0 1 2 km
Farallon de Medinilla
0 1 2 km
Rota
0 3 6 km
Benthic Habitat
Coral
Coralline Algae
Macroalgae
Land
Turf Algae
Uncolonized
Unknown

*Figure 14.17. Nearshore benthic habitat maps were released in 2005 by CCMA-BB based on visual interpretation of IKONOS satellite imagery. Source: CCMA-BB, 2005. Map: K. Buja.*

In late 2004 PIFSC-CRED scientists worked in Saipan to collect optical validation data in the Garapan anchorage as part of an assessment of bottom types in the area, and produced a report documenting this work (PIFSC-CRED, 2005). A towed camera system was deployed to collect 123 linear km (75 miles) of video footage. Figure 14.18 presents the results of an analysis of these video data in terms of coral cover percentage along the video tracks. Analysis of the optical validation data has produced GIS shape files that contain information on substrate types and other parameters. Findings are available for download from the Pacific Islands Benthic Habitat Mapping Center Web site at http://www.soest.hawaii.edu/pibhmc/pibhmc_cnmi.htm.

Using these processed multibeam and optical validation data, analyses of sand versus non-sand habitats and percent coral cover in non-sand habitats were conducted (Figure 14.19). The interpolated percent coral cover values were derived by kriging the classified optical validation (video) data. The yellow/red color gradient in this figure represents percent coral cover on the reef, and purple areas indicate sand substrate, and therefore 0% coral cover. The underlying base (gray) layers are hillshades derived from multibeam bathymetry on top of NOAA nautical charts.

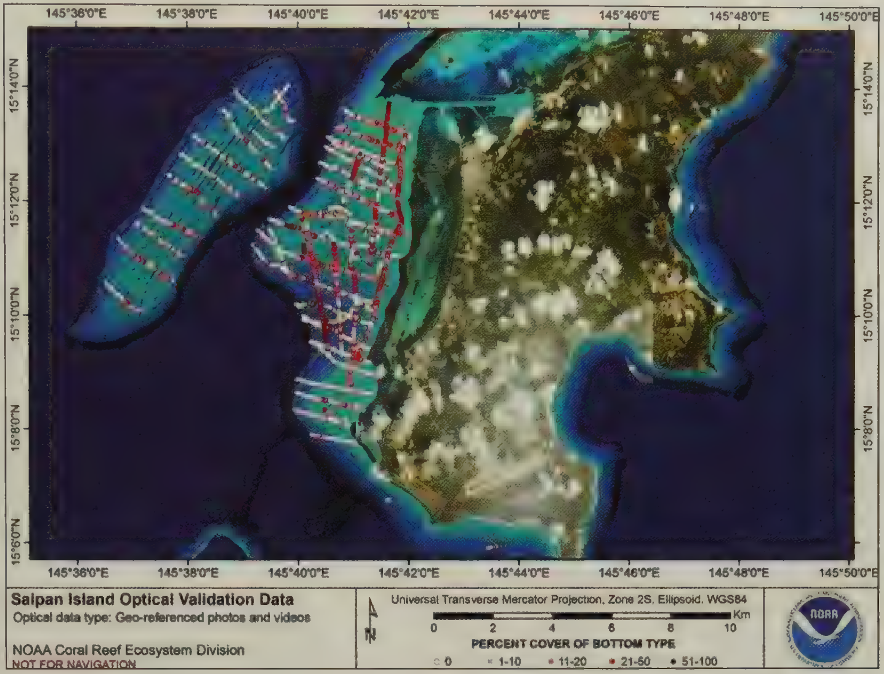

145°36'0"E
145°38'0"E
145°40'0"E
145°42'0"E
145°44'0"E
145°46'0"E
145°48'0"E
145°50'0"E
15°14'0"N
15°12'0"N
15°10'0"N
15°8'0"N
15°6'0"N
Saipan Island Optical Validation Data
Optical data type: Geo-referenced photos and videos
NOAA Coral Reef Ecosystem Division
NOT FOR NAVIGATION
Universal Transverse Mercator Projection, Zone 2S, Ellipsoid, WGS84
0
2
4
6
8
10
Km
N
PERCENT COVER OF BOTTOM TYPE
0
1-10
11-20
21-50
51-100
NOAA

Figure 14.18. Video data (123 km) were collected and classified according to percent cover of bottom type. Source: PIFSC-CRED.

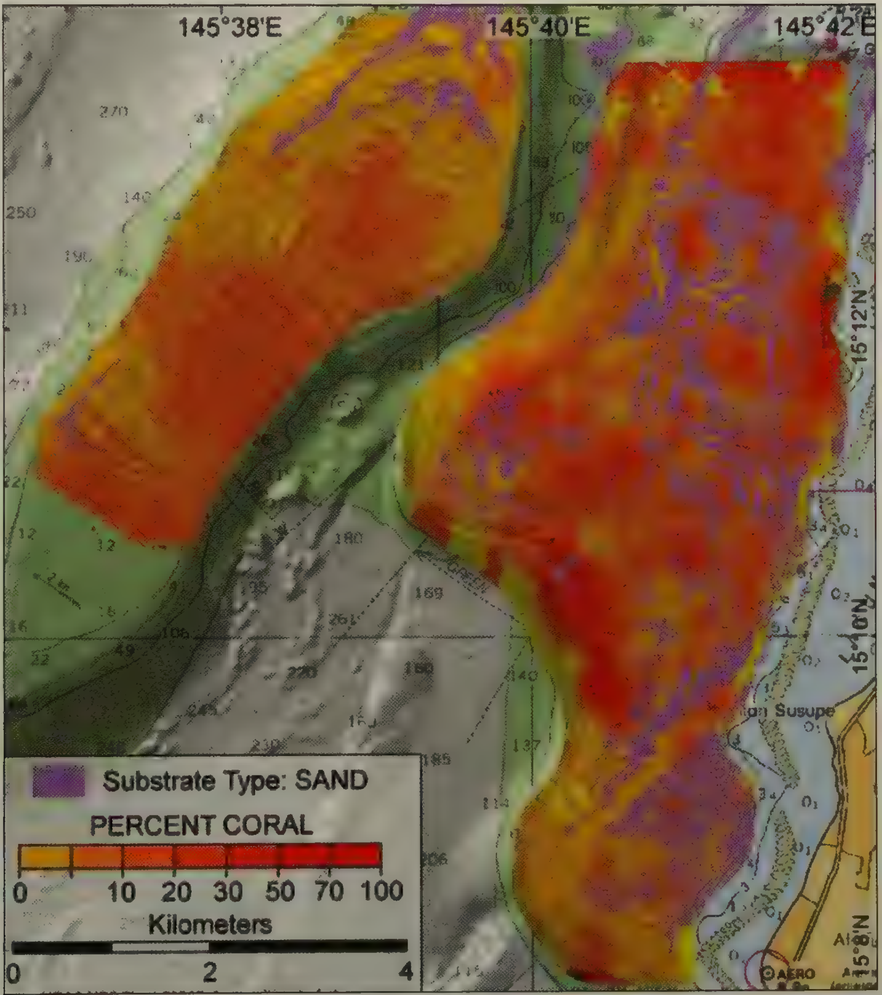

145°38'E
145°40'E
145°42'E
15°12'N
15°10'N
15°8'N
Susupe
AERO
Substrate Type: SAND
PERCENT CORAL
0
10
20
30
50
70
100
Kilometers
0
2
4

Figure 14.19. Sandy basins and interpolated values of live coral cover in the Saipan Anchorage. Source: PIFSC-CRED.

In 2007 during the biennial MARAMP cruises HI0702 and HI0703, multibeam bathymetry and backscatter data were collected around Rota (Figure 14.20), Tinian, Aguijan, Saipan (Figure 14.21), Sarigan, Zealandia Bank, Guguan, Alamagan, Pagan, Agrihan, Asuncion, Maug, Supply Reef, and Uracas (Figure 14.22). Shallow sonar data (10-300 m, 30-1,000 ft) were collected using the R/V *Acoustic Habitat Investigator (AHI)*, while overlapping and deeper sonar data (200-3,000 m, 650-9,850 ft.) were collected using the NOAA Ship *Hi'ialakai*. All maps shown here are in draft form because only preliminary processing was completed aboard ship; further processing is underway. In addition to the data shown here, which was collected primarily for coral ecosystem habitat analysis, the R/V *AHI* was also used by scientists from PIFSC-CRED in collaboration with personnel from NOAA's Office of Coast Survey to survey and update nautical charts for Saipan, Tinian and Rota harbors. The 2007 data are also being integrated into a project by NOAA's Ocean Exploration program to synthesize all available data in the Mariana Archipelago to produce a consistent bathymetric data set for the region.

Local mapping efforts have concentrated on habitat mapping within Saipan Lagoon. These activities have received support through funding from EPA and NOAA's National Coral Reef Ecosystem Monitoring Program grants and General Coral Reef Conservation grants. The mapping project was started in 2001 and fieldwork was completed in 2005. Ground based mapping methods and results of these efforts are reported in Houk and van Woesik (2008). While final map products for the southern lagoon are now being finalized, an interactive Web site provides an introduction to habitats in the northern lagoon (http://www.cnmicoralreef.net/sl/northlagoon.htm). Habitat classifications are now being used by the MMT to guide placement of monitoring sites within the lagoon using a stratified random sampling approach.

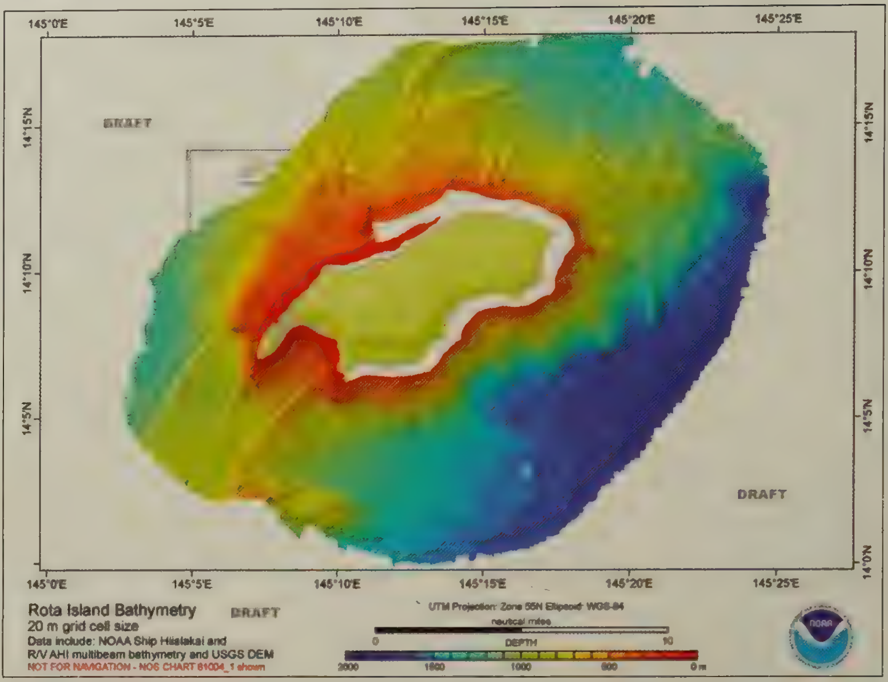

145°0'E
145°5'E
145°10'E
145°15'E
145°20'E
145°25'E
14°15'N
14°10'N
14°5'N
14°0'N
DRAFT
DRAFT
Rota Island Bathymetry
DRAFT
20 m grid cell size
Data include: NOAA Ship Hiialakai and
R/V AHI multibeam bathymetry and USGS DEM
NOT FOR NAVIGATION - NOS CHART 81004_1 shown
UTM Projection: Zone 55N Ellipsoid: WGS-84
nautical miles
0
10
DEPTH
2000
1500
1000
500
0 m

Figure 14.20. Multibeam data collected for Rota. Source: PIFSC-CRED.

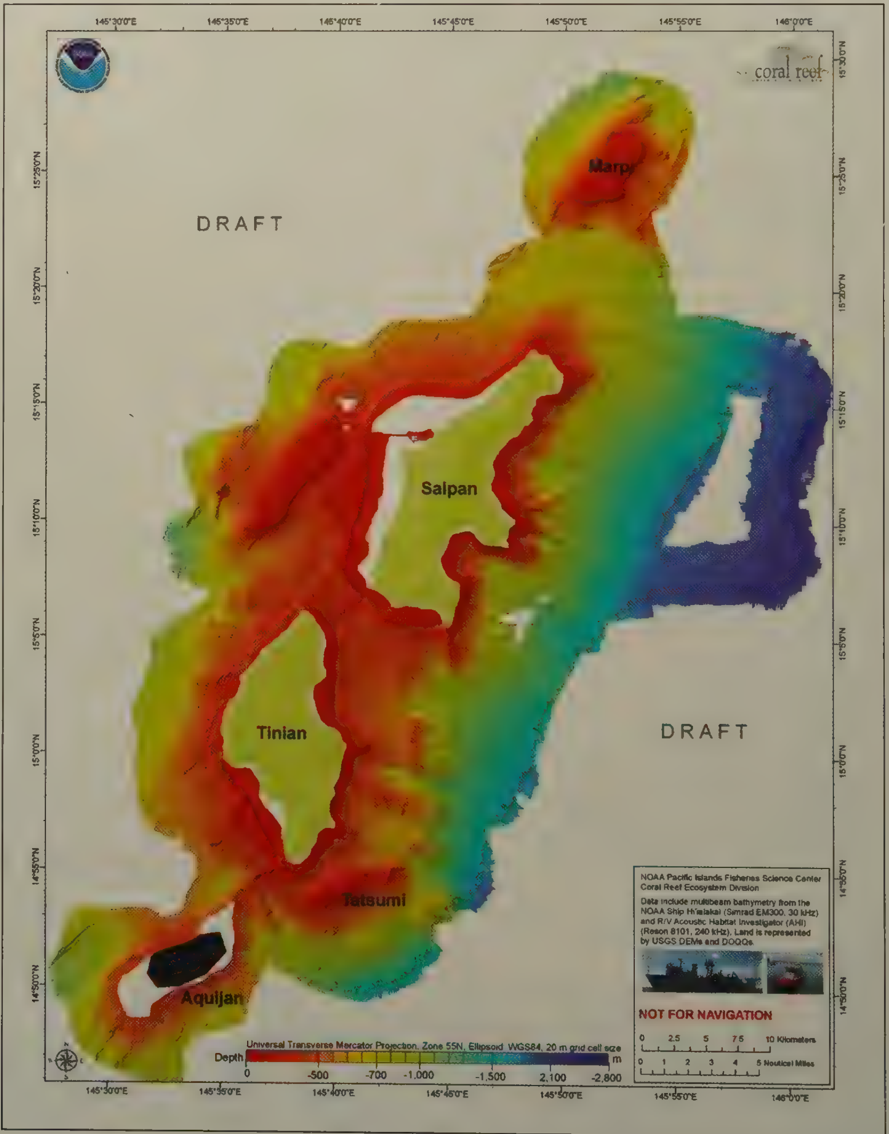
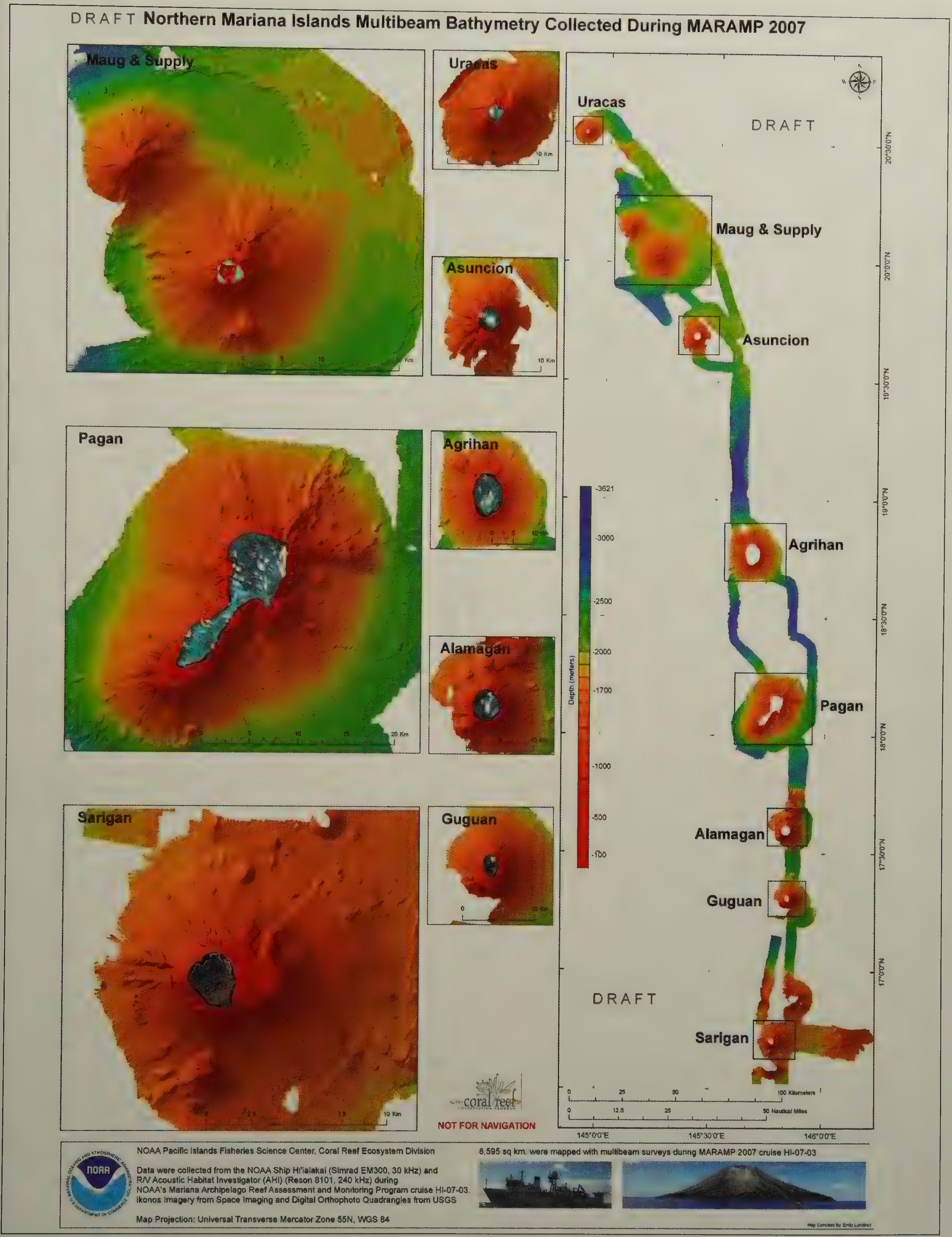

145°30'0"E
145°35'0"E
145°40'0"E
145°45'0"E
145°50'0"E
145°55'0"E
146°0'0"E
15°30'0"N
15°25'0"N
15°20'0"N
15°15'0"N
15°10'0"N
15°5'0"N
15°0'0"N
14°55'0"N
14°50'0"N
coral reef
Marpi
DRAFT
Saipan
Tinian
DRAFT
Tatsumi
Aquijan
NOAA Pacific Islands Fisheries Science Center
Coral Reef Ecosystem Division
Data include multibeam bathymetry from the NOAA Ship Hi'ialakai (Simrad EM300, 30 kHz) and R/V Acoustic Habitat Investigator (AHI) (Reson 8101, 240 kHz). Land is represented by USGS DEMs and DOQQs.
NOT FOR NAVIGATION
0
2.5
5
7.5
10 Kilometers
0
1
2
3
4
5 Nautical Miles
Universal Transverse Mercator Projection, Zone 55N, Ellipsoid WGS84, 20 m grid cell size
Depth
m
0
-500
-700
-1,000
-1,500
2,100
-2,800

Figure 14.21. Multibeam data collected for Saipan, Tinian and Agijuan. Source: PIFSC-CRED.


DRAFT Northern Mariana Islands Multibeam Bathymetry Collected During MARAMP 2007
Maug & Supply
Uracas
Asuncion
Pagan
Agrihan
Alamagan
Sarigan
Guguan
DRAFT
Depth (meters)
-3621
-3000
-2500
-2000
-1700
-1000
-500
-100
20°30'0"N
20°0'0"N
19°30'0"N
19°0'0"N
18°30'0"N
18°0'0"N
17°30'0"N
17°0'0"N
145°0'0"E
145°30'0"E
146°0'0"E
0 25 50 100 Kilometers
0 12.5 25 50 Nautical Miles
0 5 10 Km
0 5 10 15 20 Km
0 2.5 7.5 10 Km
coral reef
NOT FOR NAVIGATION
NOAA

NOAA Pacific Islands Fisheries Science Center, Coral Reef Ecosystem Division

Data were collected from the NOAA Ship Hi'ialakai (Simrad EM300, 30 kHz) and R/V Acoustic Habitat Investigator (AHI) (Reson 8101, 240 kHz) during NOAA's Mariana Archipelago Reef Assessment and Monitoring Program cruise HI-07-03. Ikonos Imagery from Space Imaging and Digital Orthophoto Quadrangles from USGS

Map Projection: Universal Transverse Mercator Zone 55N, WGS 84

8,595 sq km. were mapped with multibeam surveys during MARAMP 2007 cruise HI-07-03

Map Compiled By Emily Lundblad

*Figure 14.22. A composite of all PIFSC-CRED multibeam data available in the remote Northern Mariana Islands. Source: PIFSC-CRED.*

## ASSOCIATED BIOLOGICAL COMMUNITIES

### Coral Reef Fishes

Three programs currently conduct in-water fish monitoring surveys in the CNMI. The DFW Fisheries Research Section has conducted annual surveys of two marine protected areas, Managaha Marine Conservation Area (MMCA) on Saipan and Sasanhaya Bay Fish Reserve (SBFR) on Rota, since 2000. The CNMI Marine Monitoring Team (MMT) has included annual fish surveys as part of their long-term monitoring protocol since 2000 at sites around Rota, Tinian, Saipan and Aguijan. The NOAA PIFSC-CRED began fish surveys throughout the archipelago during the initial MARAMP cruise in 2003 and has repeated surveys on a two-year cycle. In addition to in-water surveys, the DFW Fisheries Data Section collects monthly commercial fish catch data provided by fish vendors, which provides a direct measure of fisheries pressure on local coral reef fish resources. In the following sections, data from DFW and PIFSC-CRED are provided.

On an archipelagic scale, PIFSC-CRED found that fish assemblages around the CNMI in 2005 were essentially similar to that found during the MARAMP cruise two years prior (Starmer et al., 2005). The general trend recorded by towed-diver surveys indicates a greater biomass of larger fish in the northernmost islands (0.25 ton ha$^{-1}$) compared to the middle section of the island chain (0.13 ton ha$^{-1}$) and the heavily populated southern islands (0.05 ton ha$^{-1}$; Figure 14.23). Large fish biomass was moderately abundant on the western banks (0.10 ton ha$^{-1}$). A similar pattern was observed by the REA team conducting stationary point count surveys at monitoring sites (Figure 14.24) In general, sharks were scarce throughout the archipelago, but slightly more common at Asuncion, Zealandia, Agrihan and Pathfinder. The most common fishes were damsels and small wrasses, especially in the southern islands, and many species exhibited good recruitment pulses (e.g., *Chromis acares*, *C. vanderbilti*, *Pomacentrus vaiuli*). A few individual Napoleon wrasse (*Cheilinus undulatus*), including some large ones, were seen around the mid-chain and in the southern islands. Bumphead parrotfish (*Bolbometopon muricatum*) were not seen in 2005, although several were seen in the archipelago in 2003. The size class distribution of targeted species (snappers, jacks, groupers and sharks) showed low numerical density in Guam and the Southern Islands, especially for fish larger than 20 cm (Figure 14.25).

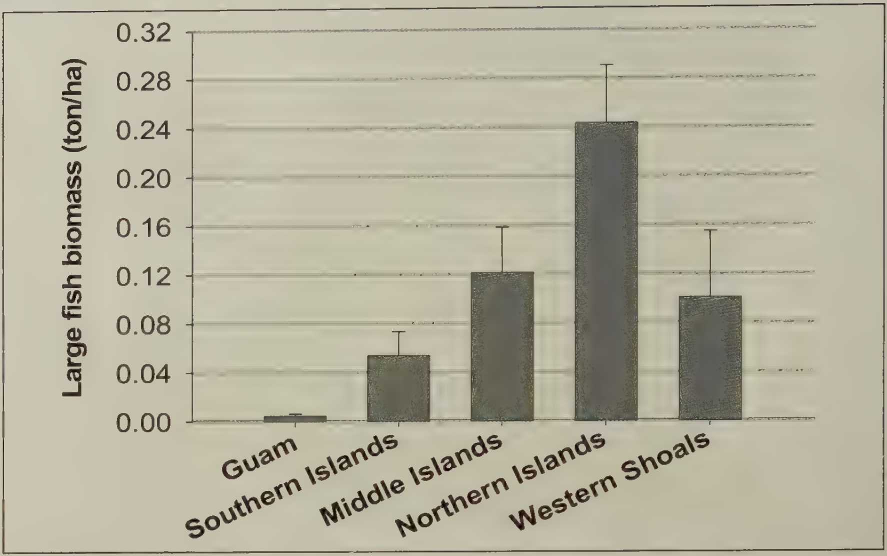


Figure 14.23. Large (>50 cm) fish biomass as observed in towed-diver surveys across the Marianas Archipelago. Source: PIFSC-CRED, unpub. data.

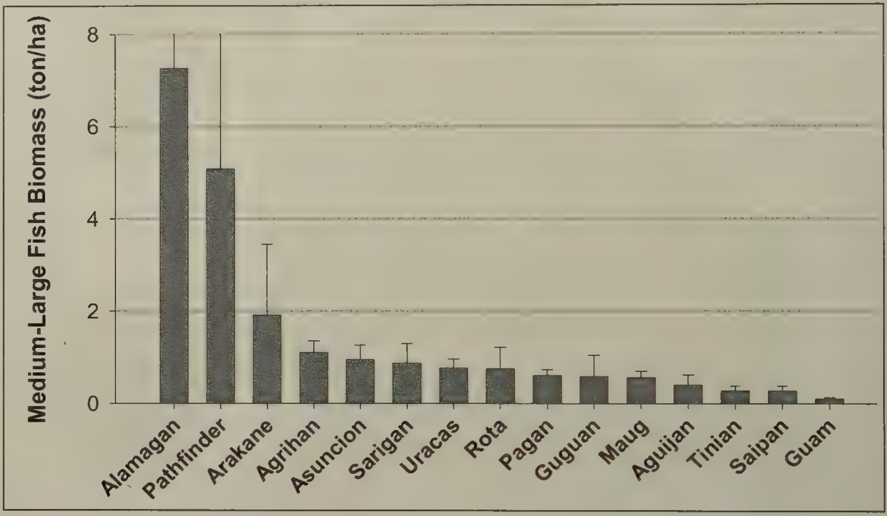


Figure 14.24. Medium-large (>25 cm) fish biomass recorded in Stationary Point Counts across the Marianas Archipelago. Source: PIFSC-CRED, unpub. data.

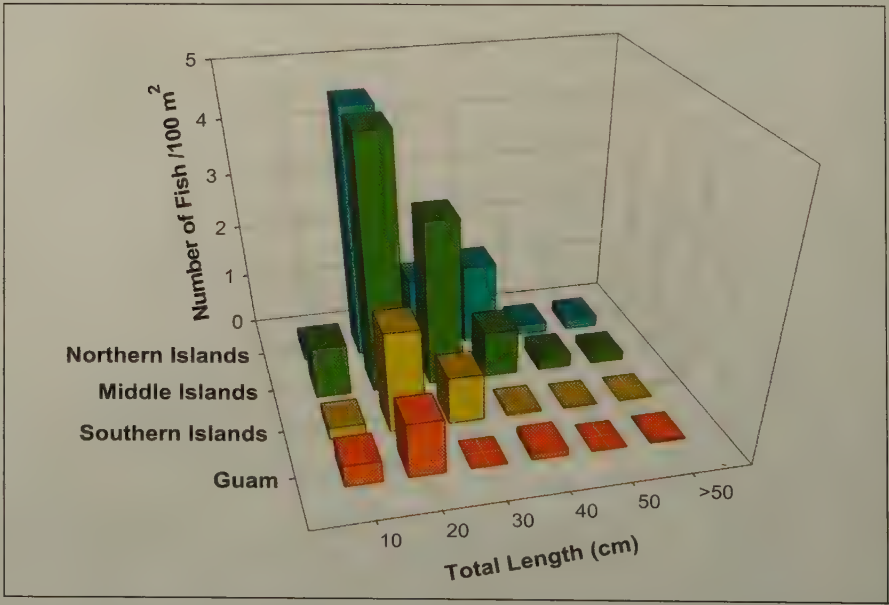


Figure 14.25. Numerical density of targeted families (snappers, jacks, groupers, and sharks) by size class measured on belt transects across the Marianas Archipelago. Source: PIFSC-CRED, unpub. data.

Within the MMCA and SBFR, DFW belt transect surveys identified generally positive trends in surveyed fish populations. The data shown in Figure 14.26 show relative population estimates of 12 food fish groups over time in the MMCA and SBFR. Data collection was allocated according to a stratified random sampling approach using the four primary habitats where transect data has been demonstrated to be useful; the reef slope, lagoon deep patch reef, lagoon shallow patch reef/*Acropora* zone, and the mixed area. For SBFR, the graphs of relative population over the 2000-2006 survey period indicate positive upward trends for the Lutjanidae, Mullidae, Nasinae, Serranidae, roving Acanthuridae, and initial and terminal phase Scaridae. No trends are evident among Balsitidae, Holocentrinae, Myripristinae, Lethrinidae and sedentary Acanthuridae. Within the MMCA, Lutjanidae and Nasinae did not exhibit a detectable trend, but all other surveyed groups exhibited populations increases, especially over the last two survey years.

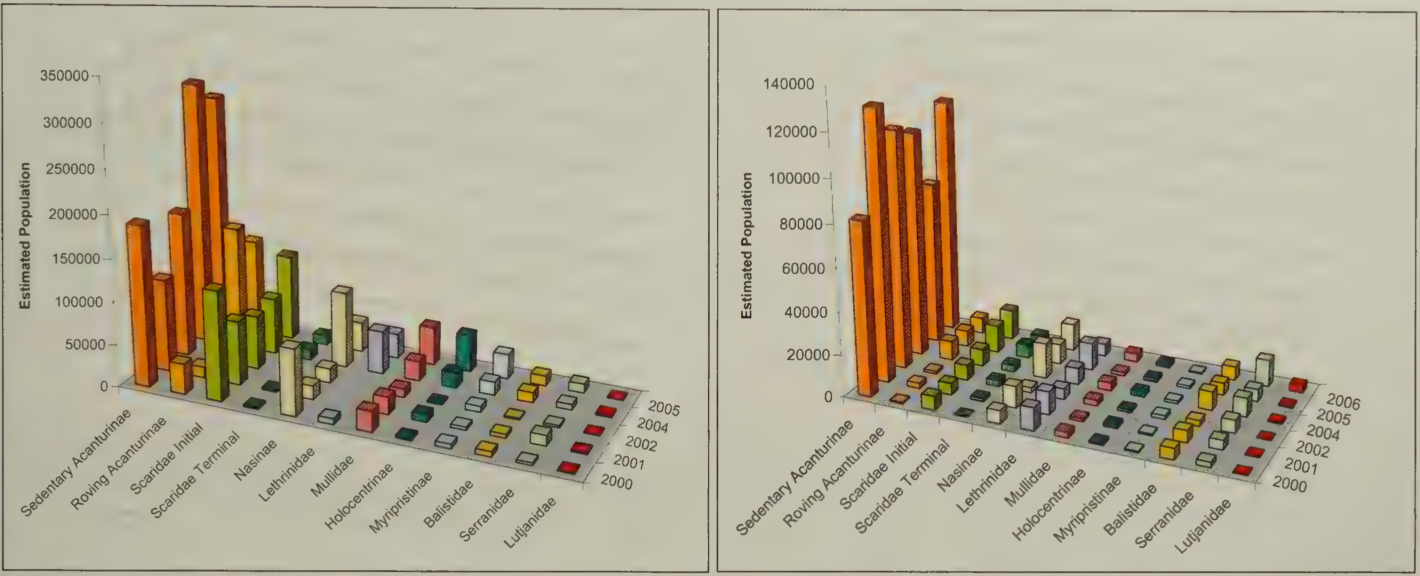


*Figure 14.26. Belt transect survey data from stratified random sampling at MMCA (left) and SBFR (right), agglomerated from the primary habitats where transect data has been demonstrated to be useful. Source: CNMI DFW.*

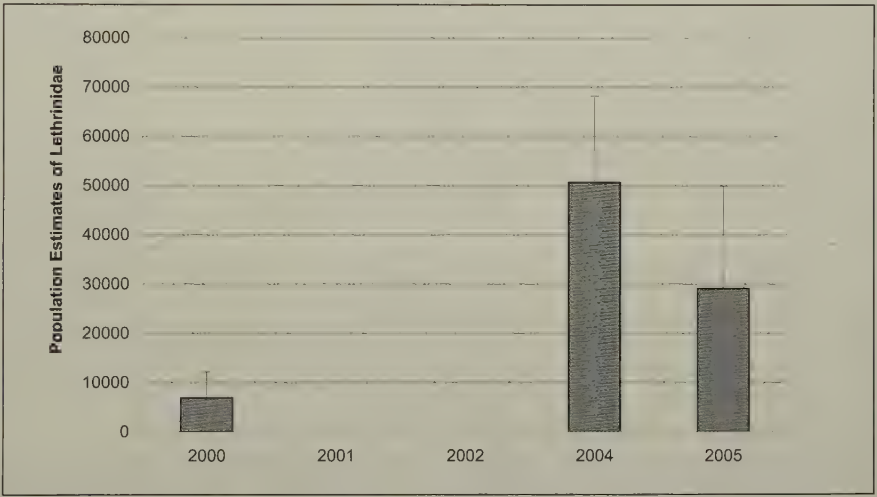


*Figure 14.27. Belt transect data for Lethrinidae in MMCA on Saipan from a set of pooled sampling strata. Source: CNMI DFW.*

Regular enforcement began in late 2002, which DFW believes to be directly attributable to the enhancement of reef fish resources within the MMCA. The institution of regulatory restrictions on the use of gill, drag and surround nets in 2003 have also enhanced the MMCA and probably the entire lagoon in general, as these methods of harvest were most prevalent in the Saipan Lagoon. In addition, the ban on the use of SCUBA spear fishing on Saipan in 2003 has also improved the abundance of food fish groups. As an example, relative population estimates of Lethrinidae in Figure 14.27 indicate a positive trend over the past two years, which are attributable to *Gnathodentex aurolineatus* and *Lethrinus harak* becoming more abundant since the inception of prohibitions on use of scuba spear and nets. Both species were landed in high numbers during the scuba spear fishery (Graham, 1994; Trianni, 1998), and *L. harak* has comprised as much as 40% of recent exemptions to the net prohibition (DFW, unpub. data). It can be considered that the increase in abundance of *L. harak* was due not only to the MMCA but also to the scuba spear and net prohibitions, as this species travels widely throughout the lagoon, whereas the increase in *G. aurolineatus* is more likely due to the MMCA and the scuba spear ban.

Although the SBFR was created in 1994, little management action occurred until March 2000, when the DFW formally demarcated the boundaries with marker buoys. Even with the lack of adequate enforcement in the SBFR, seven of the twelve groups surveyed demonstrate an upward trend over time. More importantly, no groups indicated a negative trend. There is no clear indication of the reasons for either trend, although there may have been a self-governed harvest restraint practiced by some percentage of the Rota fishing community. The lack of real trends in nearly half of the groups may be indicative of a relatively stable fish community, with observed increasing trends merely natural variability.

The DFW Fisheries Data Section provides monthly catch data to NOAA PIFSC's WPacFin program, which maintains fisheries data across the Pacific and is available at http://www.pifsc.noaa.gov/wpacfin/cnmi/Pages/cnmi_data_1.php. These data are provided by Saipan fish vendors to DFW. The robustness and coverage of the data, especially in early years of the program, was less than complete. As a result, catch data are adjusted to 100% and reported as estimates. Figure 14.28 illustrates the importance of reef fish to the fisheries industry on Saipan. While most reef fish are reported as management units and combined with non-reef associated taxa, rabbitfish, parrotfish and spiny lobster (Figure 14.29) are reported individually.

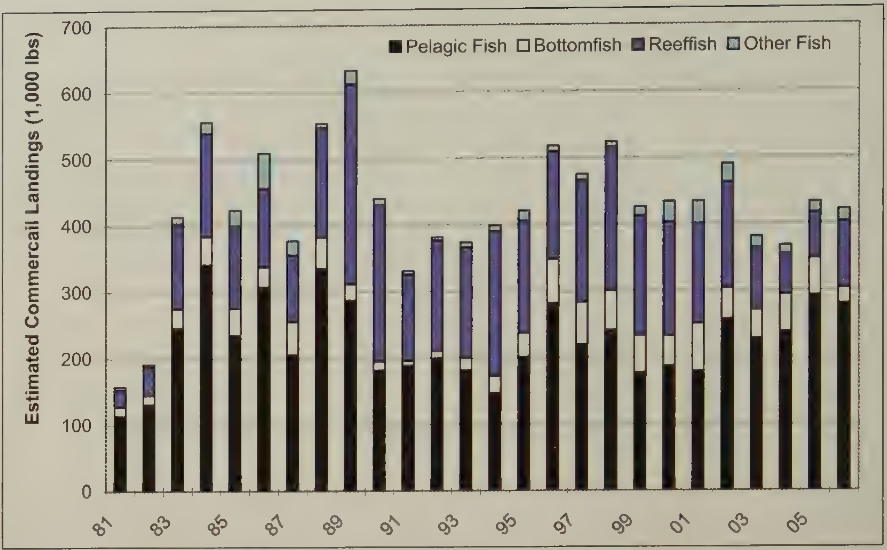


*Figure 14.28. Annual estimated commercial landings of fish for Saipan, 1981-2006. Source: WestPacFin.*

## Invertebrates

As with fishes, the MMT, DFW and PIFSC-CRED have conducted invertebrate surveys in CNMI. DFW concentrates monitoring efforts on finfish and has paid sporadic attention to specific taxa of fisheries interest, sea cucumbers and *Trochus*, but does not consistently monitor these resources. Inconsistencies in the application of PIFSC-CRED's REA survey methods, used during MARAMP cruises, hamper the use of this program's invertebrate data for monitoring trends in abundance. However, the PIFSC-CRED towed-diver surveys provide an overview of areas of notable COTS abundance, as described in the benthic status section above. MMT data have also identified peaks in COTS abundance at long-term monitoring sites: Barcinas Bay at Tinian in 2003 and Wing Beach at Saipan in 2005 (Figure 14.30).

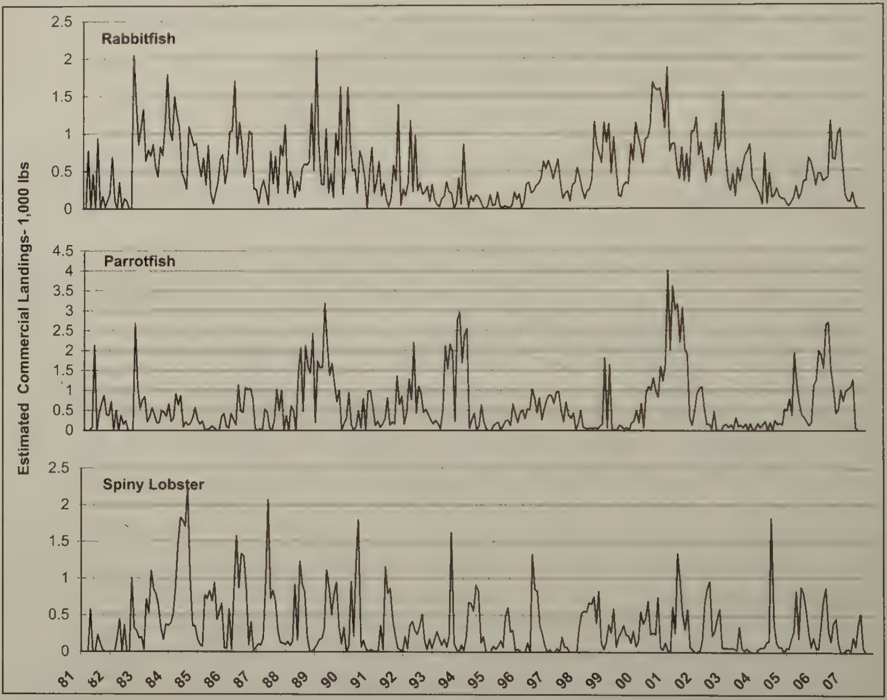


*Figure 14.29. Estimated commercial landings from Saipan, 1981-2008. Source: WestPacFin.*

The CNMI's long-term monitoring program has collected data on macroinvertebrate abundances on an annual basis at most fore reef survey sites. Most sites have exhibited remarkable year-to-year variation in invertebrate abundances (Figure 14.30). Unfortunately, even abrupt changes in species composition, as were observed in 2005-2006 at Rota's Sasanhaya and West Harbor do not to have obvious environmental correlates. With the exception of *Tridacna* clams, the majority of taxa included in the study are not harvested at survey sites, so the variation may simply be the result of stochastic variation in recruitment.

The MMT is further extending its invertebrate monitoring effort to reef flats, deeper fore reefs and habitats within the Saipan Lagoon to gain an improved understanding of invertebrate spatial distribution. While few of these novel sites have been revisited and none have sufficient temporal coverage to provide trend data, these habitats are proving to be less diverse than fore reef habitats, though abundances of some taxa, especially sea cucumbers, are exceedingly high in lagoon habitats.

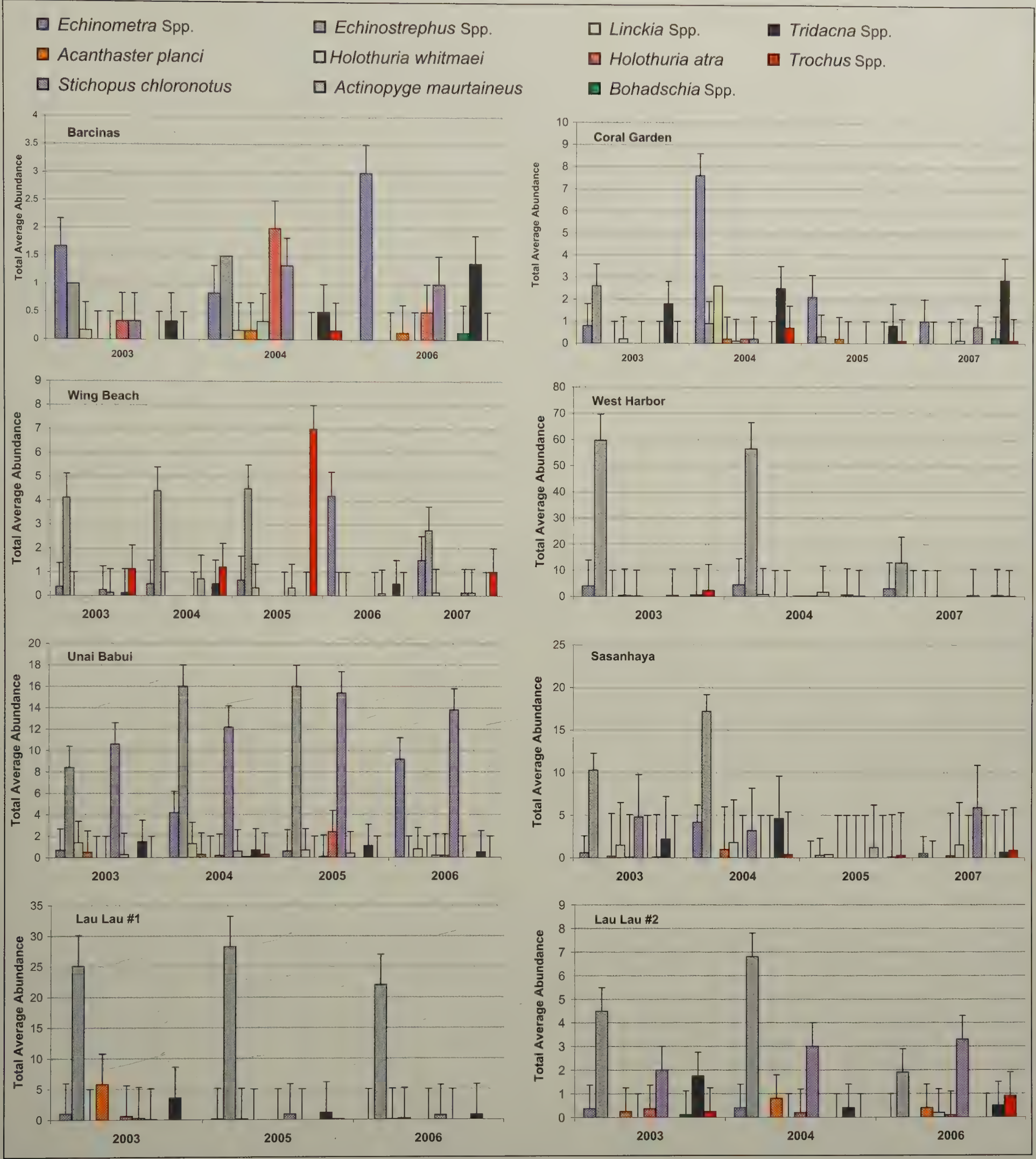


Figure 14.30. Abundance of macroinvertebrates expressed as average per 100 m$^2$ at 8 m depth fore reef MMT long-term monitoring sites. Source: CNMI MMT.

## CURRENT CONSERVATION MANAGEMENT ACTIVITIES

### Micronesia Challenge

In March 2006, the President of Palau launched the Micronesia Challenge (MC) at the Eighth Conference of Parties to the Convention of Biological Diversity to promote efforts to effectively conserve 30% of marine resources and 20% of the terrestrial resources by 2020. Five political entities of Micronesia, including the CNMI Governor, signed on to the MC Declaration of Commitment. The MC is designed to build on ongoing conservation work in each jurisdiction and increase access to critically needed resources, regional coordination and cooperation. Local environmental agency representatives attended an organizational meeting in Palau later that year. While most other signatory jurisdictions are focusing efforts on Marine Protected Area designations, the CNMI's approach is more general and is focusing on marine resource status and NPS pollution issues along with consideration of place-based management efforts.

### U.S. Coral Reef Initiative (CRI)

The CNMI continues to actively participate in U.S. Coral Reef Initiative (CRI) activities. Interagency management efforts have been focused more clearly through the LAS development and implementation. Since its development in 2003, the LAS have been in an implementation stage. The LAS process has been important in identifying management gaps and providing tangible benchmarks to address those gaps. CNMI continues to utilize the LAS to address problems affecting coral reefs, and is in the process of developing a new round of LAS to further address current threats. The 2003 CNMI Coral Reef LAS are currently being evaluated and revised. The CNMI LAS focus on fisheries management, land-based sources of pollution, public use and misuse, public awareness and involvement and coral reef resource management. The LAS has been the primary guide for design of implementation projects. One major by-product of the LAS was the directive issued by the governor establishing an interagency coordinating structure for the local CRI programs. This structure includes a director-level policy committee, and interagency coordination and science advisory committees. Further information about the CNMI CRI efforts and LAS is available at http://www.cnmicoralreef.net.

In addition to local government participation in federal grant programs, such as the Coral Reef Management and Coral Reef Ecosystem Monitoring Grants, several General Coral Reef Conservation grants have been awarded to local non-governmental organizations (NGOs). These grants have provided a remarkable boost to local coral reef conservation capacity over the past six years. The local marine sanctuary enforcement program is almost entirely funded through these programs (see next section below), and the entire CRM coral monitoring program is similarly supported by CRI funds.

### Marine Protected Area Programs

The Marine Protected Areas (MPA) program, managed by DFW, continues to make strides in building its capacity to effectively manage CNMI's MPAs, in large part due to the support provided by the Coral Reef Management Grants. The no-take Mañagaha Marine Conservation Area (MMCA) is the most commonly recognized MPA in the CNMI because it is a very popular tourist attraction. MMCA lies in the protected Saipan Lagoon and is an important part of the cultural history of the CNMI's Carolinian inhabitants. Although it was established in August 2000, effective enforcement required additional staff and equipment. Starting in September 2002, the NOAA Coral Reef Conservation Program provided the necessary funds for enforcement staff and equipment. The federal funding was used to hire three local agency marine conservation officers to enforce the MPA laws on Saipan, and they began to hand out citations for violations in 2003. At the same time, education efforts were initiated, including ads in local magazines, publication of brochures, educational signs, school presentations, and fishermen's forums to discuss fishery issues, such as MPAs.

In contrast, the no-take Sasanhaya Bay Fish Reserve (SBFR) in Rota was established in 1994, and additional enforcement staff were never made available for the site. Outreach efforts were also limited. Unpublished research from DFW's Fisheries Research Section suggests a possible difference in fishery recovery rates between the two MPAs. Fisheries biologists began seeing positive trends in the size of certain fish species in the MMCA, while such trends have not been observed in the SBFR. Although it is difficult to account for all of the variables that may have caused this disparity, DFW suggests the difference in enforcement presence, enforcement actions, and education efforts account for much of the difference between the recovery rates at the two sites.

CNMI now has nine MPAs, including the recent addition of a sizeable MPA (9 km, 2,200 acre) on Tinian. The CRI management grant funded the development of management plans for Bird Island and Forbidden Island Sanctuaries, which were recently approved. The plans include provisions to charge visitors fees to sustainably fund associated management programs. Nearly three years of support by a NOAA Coral Reef Fellow have provided additional capacity to the MPA program for community outreach and education on Saipan. In Rota, another NOAA Coral Reef Fellow has similarly built local support for the single MPA there. Efforts are underway to engage the community in fisheries management with the Pacific Islands Marine Protected Area Communities (PIMPAC) partnership. A recent peer learning exchange with Hawaiian and Pohnpeian fisherman in Rota and Saipan encouraged the fishing community and local agencies to work together.

### Nonpoint Source (NPS) Pollution Programs

NPS pollution has long been recognized as the major anthropogenic stressor of coral reef ecosystems in the CNMI. The NPS programs in CNMI have been collaboratively run by DEQ (funded by EPA) and CRM (funded by NOAA). The removal of all funding for the NOAA 310 grant program in the 2007 federal budget has eliminated CRM's program. However, efforts are being made to address the shortfall locally through other funding sources.

Despite this substantial setback to the CNMI NPS program, a number of major NPS projects continue to progress, primarily through EPA and LAS funds. The LAS strategies addressing land based sources of pollution focus on priority watersheds on CNMI's three most populated islands. Collaborative efforts by local government agencies and communities have revegetated areas of eroding badlands. In Talakhaya, the first two-year phase of the project focused on revegetation, which included planting of 25,000 grass and tree seedlings by local volunteers, students, and local agency staff from DLNR and DEQ. A water quality monitoring plan is in effect to determine the environmental impact the grass and tree seedlings will have on the adjacent marine area. In addition, a request was submitted the to the CNMI legislature to include the project area, estimated over 400 acres, into the existing Sabana Conservation Area. This request has been granted and the Talakhaya watershed is now a conservation area, which protects the entire watershed from extractive and illegal activities.

In Lau Lau Bay, Saipan, architectural and engineering designs have been completed to improve stream crossings along Lau Lau Bay Road to address sedimentation and runoff from badlands and secondary dirt roads. Another component of the Lau Lau Bay project is the revegetation of badlands with the assistance of hundreds of community volunteers and a Know-Your-Watershed project that educates households within the watershed about their environment. The project also recruited numerous volunteers to assist in other related activities. Other land-based pollution efforts include a completed architectural and engineering design for Obyan Beach to capture sediment runoff in five terraced ponds before it reaches the drainage overflow and the ocean. Ongoing marine water quality sampling by DEQ and nearshore and reef flat monitoring by the CNMI MMT will assess the eventual success of these efforts in mitigating NPS stressors at these sites.

A steady increase in 4x4 motor vehicle sales since the economic boom of the late 1980s has led to an increase in vehicular traffic on CNMI beaches, especially around Saipan. The steady beach traffic has resulted in compacted sand, destroyed turtle nesting sites, introduction of petroleum products to the nearshore environment, and destroyed beach vegetation leading to increased erosion and uncontrolled runoff from upland watersheds. In response, natural resources agencies began the "Walk it, Don't drive it" beach campaign in late 2001. The campaign has educated the community about the importance of beach vegetation and the harmful impacts of vehicular traffic on the nearshore environment and aquatic ecosystems. The campaign has successfully gained community support for closing two area beaches to vehicular traffic, the first in 2004 and the second in 2007. Both efforts were funded through a grant from the U.S. Fish and Wildlife Service. The beaches have since recovered, and once again nests of threatened green sea turtles have successfully hatched on their shores (Figure 14.31).

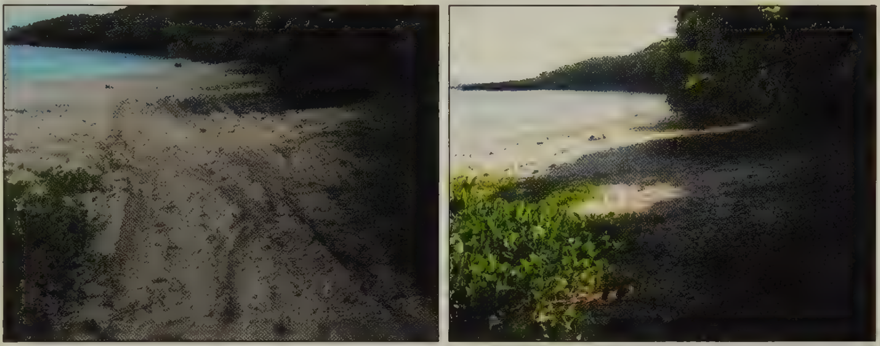


*Figure 14.31. Photographs of Wing Beach, Saipan prior to installing bollards and a gate in 2004 (left) and a year after closing access to vehicles (right). Photo: K. Yuknavage.*

## OVERALL CONCLUSIONS AND RECOMMENDATIONS

Largely thanks to funding provided by the U.S. Coral Reef Initiative (CRI), the CNMI's capacity to manage its coral reef ecosystem resources effectively has grown substantially over the past seven years. The overall understanding of CNMI's coral reef ecosystems is just approaching the point where management activities can be quantitatively evaluated through monitoring and other assessment programs. The CNMI's capacity to assess, monitor, educate and enforce coral reef management policy has grown substantially through an increase in both personnel and the development of locally applicable management tools.

Local and federal monitoring and assessment programs have made remarkable strides in addressing gaps in bathymetric and benthic mapping as well as assessment and monitoring of large and small scale habitat variability. While monitoring protocols continue to improve, capacity to carry out *in situ* surveys remains a limiting factor given the size of the Commonwealth and the limited number of trained personnel and transport options available in the CNMI. Support continues to grow for validating remote sensing tools such as satellite and video habitat assessment and monitoring and for the development of an integrated system of unattended environmental monitoring stations for the archipelago.

As the CNMI moves toward identifying and addressing gaps in knowledge and management capacity, the local CRI program will continue to ensure activities remain relevant to coral reef management. The CNMI's critical goals are the development of justifiable performance indicators and programmatic self-sufficiency. The LAS have played a large part in the development of performance indicators, but the programmatic self-sufficiency is just beginning to be realized through activities associated with fulfilling the Micronesia Challenge.

## REFERENCES

Bearden, C., R. Brainard, T. de Cruz, R. Hoeke, P. Houk, S. Holzwarth, S. Kolinski, J. Miller, R. Schroeder, J. Starmer, M. Timmers, M. Trianni, and P. Vroom. 2005. The State of Coral Reef Ecosystems of the Commonwealth of the Northern Mariana Islands. pp. 399-441. In: J.E. Waddell (ed.). The State of Coral Reef Ecosystems of the United States and Pacific Freely Associated States: 2005. NOAA Technical Memorandum NOS NCCOS 11. Silver Spring, MD. 522 pp.

Becerro, M.A., V. Bonito, and J.P. Valerie. 2006. Effects of monsoon-driven wave action on coral reefs of Guam and implications for coral recruitment. Coral Reefs (25): 193-199.

CCMA-BB. 2005. Shallow-water Benthic Habitats of American Samoa, Guam, and the Commonwealth of the Northern Mariana Islands. NOAA Technical Memorandum NOS NCCOS 8. Silver Spring, MD. 126 pp. http://ccma.nos.noaa.gov/products/biogeography/us_pac_terr/index.htm.

Cloud, P.E. 1959. Geology of Saipan, Mariana Islands, Part 4. Submarine topography and shoal-water ecology. Geological Survey Professional Paper 280-K: 361-445.

Fabricius, K. 2005. Effects of terrestrial runoff on the ecology of corals and coral reefs: review and synthesis. Mar. Poll. Bull. 50: 125-146.

Gardner, J.V. 2006, U.S. Law of the Sea Cruise to Map the Western Insular Margin and 2500-m isobath of Guam and the Northern Mariana Islands. Technical Report 06-100. Center for Coastal and Ocean Mapping/Joint Hydrographic Center, University of New Hampshire. Durham, NH. 37 pp.

Graham, T. 1994. Biological Analysis of the Nearshore Reef Fish Fishery of Saipan and Tinian. Commonwealth of the Northern Mariana Islands, Saipan. Department of Fish and Wildlife Technical Report 94 (02): 1-124.

Hoegh-Guldberg, O. 1999. Climate change, coral bleaching and the future of the world's coral reefs. Mar. Freshw. Res. 50(8): 839-866.

Houk, P. 2006. Spatial distribution of coral reef communities and reef growth in the Commonwealth of the Northern Mariana Islands. Ph.D. Dissertation. Florida Institute of Technology. Melbourne, FL.

Houk P., G. Didonato, J. Iguel, and R. van Woesik. 2005. Assessing the effects of nonpoint source pollution on American Samoa's coral reef communities. Environ. Monit. Assess. 107: 11-27.

Houk, P., S. Bograd, and R. van Woesik. 2007. The transition zone chlorophyll front can trigger *Acanthaster planci* outbreaks in the Pacific Ocean: historical confirmation. J. Oceanogr. 63: 149-154.

Houk, P. and R. van Woesik. In press. Changes in the Saipan Lagoon since 1959: towards understanding causal relations. Mar. Ecol. Prog. Ser.

Houk, P. and R. van Woesik. Submitted. Coral assemblages and Holocene reef growth in the Commonwealth of the Northern Islands. Ecography.

Hughes, T.P., A.H. Baird, D.R. Bellwood, M. Card, S.R. Connolly, C. Folke, R. Grosberg, O. Hoegh-Guldberg, J.B.C. Jackson, J. Kleypas, J.M. Lough, P. Marshall, M. Nystrom, S.R. Palumbi, J.M. Pandolfi, B. Rosen, and J. Roughgarden. 2003. Climate Change, Human Impacts, and the Resilience of Coral Reefs. Science 301(5635): 929-933.

Jokiel, PL, C.L. Hunter, S. Taguchi, and L. Watarai. 1993. Ecological impact of a fresh-water "reef kill" in Kaneohe Bay, Oahu, Hawaii. Coral Reefs 12: 177–184

Kleypas, J.A., R.W. Buddemeier, D. Archer, J. Gattuso, C. Langdon, and B.N. Opdyke. 1999. Geochemical Consequences of Increased Atmospheric Carbon Dioxide on Coral Reefs. Science 284(5411): 118-120.

Landers, M.A. 2004. Rainfall Climatology for Saipan: Distribution, Return-periods, El Nino, Tropical Cyclones, and Long-term Variations. Technical Report 103. Water and Environmental Research Institute of the Western Pacific, University of Guam. Mangilao, Guam. 103 pp.

McPhaden, M.A., R. Busalacchi, J. Cheney, K. Donguy, D. Gage, M. Halpern, P. Ji, G. Julian, G. Meyers, P. Mitchum, J. Niiler, R. Picaut, N. Reynolds, N. Smith and K., Takeuchi. 1998. The Tropical Ocean-Global Atmosphere observing system: A decade of progress. J. Geophys. Res. 103(14): 169-240.

Minton, D. and A. Palmer. 2006. Historical Record of Tropical Cyclones of Saipan, Commonwealth of the Northern Mariana Islands (1645-2005). Technical Report for the National Park Service.

NOAA. 2005. Final Report: Characterization of Benthic Habitat for Saipan Anchorage, Commonwealth of the Northern Mariana Islands. Coral Reef Ecosystem Division, Pacific Islands Fisheries Science Center, NOAA National Marine Fisheries Service. [restricted distribution]

Orr, J.C., V.J. Fabry, O. Aumont, L. Bopp, S.C. Doney, R.A. Feely, A. Gnanadesikan, N. Gruber, A. Ishida, F. Joss, R.M. Key, K. Lindsay, E. Maier-Reimer, R. Matear, P. Monfray, A. Mouchet, R.G. Najjar, G. Plattner, K.B. Rodgers, C.L. Sabine, J.L. Sarmiento, R. Schlitzer, R.D. Slater, I.J. Totterdell, M. Weirig, M. Yamanaka, and A. Yool. 2005. Anthropogenic Ocean Acidification over the Twenty-First Century and its Impact on Calcifying Organisms. Nature 437: 681-686.

Pacific El Nino/Southern Oscillation Applications Center (PEOAC). 2006. Pacfice ENSO Update: Current Conditions 12 (4). Honolulu, HI. 12 pp.

Preskitt, L.B., P.S. Vroom, and C.M. Smith. 2004. A rapid ecological assessment (REA) quantitative survey method for benthic algae using photo quadrats with SCUBA. Pac. Sci. 58: 201-209.

Randall, R.H. 1985. Habitat geomorphology and community structure of corals in the Mariana Islands. pp. 261-266. In: C. Gabrie and M. Harmelin (eds.). Proceedings of the 5th International Coral Reef Congress, Vol. 6. Tahiti, French Polynesia. 670 pp.

Tomczak, M. and J.S. Godfrey. 2003. Regional Oceanography: an Introduction. 2nd edition. Daya Publishing House, Delhi.

Trianni, M.S. 1998. Summary and further analysis of the nearshore reef fishery of the Northern Mariana Islands. Tech. Rept. 98-02. Department of Fish and Wildlife, Commonwealth of the Northern Mariana Islands, Saipan. 64 pp.

Tribollet, A.D. and P.S. Vroom. 2007. Temporal and spatial comparison of the relative abundance of macroalgae across the Mariana archipelago between 2003 and 2005. Phycologia 46(2): 187-197.

Valiela I. 1995. Marine Ecological Processes. Springer-Verlag, NY. 686 pp.

Vetter, O.J., 2007. Setup observations over two fringing reefs: Mokule'ia Reef, Oahu and Ipan Reef, Guam. Masters Thesis. School of Ocean and Earth Science, University of Hawaii at Manoa. Honolulu, HI.

Work, T.M. and G.S. Aeby. 2006. Systematically describing gross lesions in corals. Dis. Aquat. Org. 70: 155-160.

Yu, X. and M. McPhaden. 1999. Seasonal Variability in the Equatorial Pacific. J. Phys. Oceanogr. 29: 925-947.

# The State of Coral Reef Ecosystems of Guam

David Burdick[1], Valerie Brown[2,4], Jacob Asher[3,4], Mike Gawel[5], Lee Goldman[6], Amy Hall[3,4], Jean Kenyon[3,4], Trina Leberer[7], Emily Lundblad[3,4], Jenny McIlwain[6], Joyce Miller[3,4], Dwayne Minton[8], Marc Nadon[3,4], Nick Pioppi[6], Laurie Raymundo[6], Benjamin Richards[3,4], Robert Schroeder[3,4], Peter Schupp[6], Ellen Smith[3,4] and Brian Zgliczynski[3]

## INTRODUCTION AND SETTING

This report provides an assessment of the status of the coral reef ecosystems of Guam between 2004 and 2007. The findings of various monitoring activities, assessments, and stand-alone investigations conducted by local and federal agencies, educational/research institutions, and government contractors since 2004 were synthesized to obtain an updated, holistic view of the status of Guam's reefs.

Guam, a U.S. territory located at 13°28' N, 144°45' E, is the southernmost island in the Mariana Archipelago (Figure 15.1). It is the largest island in Micronesia, with a land mass of 560 km$^2$, and has a maximum elevation of approximately 405 m and a total shoreline length of 244 km. Guam is a volcanic island completely surrounded by a coralline limestone plateau. The relatively flat northern half of the island, which is primarily comprised of uplifted limestone, is the site of the island's principle aquifer. The southern half of the island has more topographic relief and is comprised mainly of volcanic rock, with areas of highly erodible lateritic soils. The hilly topography creates numerous watersheds drained by 96 rivers (Best and Davidson, 1981).

Guam is the most heavily populated island in Micronesia, with an estimated population in 2007 of about 173,500 (U.S. Census Bureau, 2007). In 2000, the U.S. Census Bureau predicted the population growth rate to steadily decrease over the next 50 years, but this estimate did not take into account the planned movement of roughly 26,000 additional military personnel and dependents to Guam by 2014 (Helber, Hastert and Fee, Planners, 2006). Such an influx, coupled with associated migration to Guam by those seeking economic gain from the expansion, would increase the existing population by up to 38% in less than 10 years, potentially pushing the total population to over 230,000 (Guam Civilian Military Task Force, 2007).

The island typically experiences easterly trade wind conditions (10-15 mph) and associated east-northeast ocean swell of small (1-2 m), short period (3-10 seconds) waves. The mean annual temperature on Guam is 28°C (82°F), with a mean annual rainfall of approximately 260 cm or 102 in (Lander and Guard, 2003). The dry season extends from December until June, while the wet season falls between July and November. Sea surface temperatures around Guam range from about 27-30°C, with higher temperatures measured on the reef flats and in portions of the lagoons (Paulay, 2003). Guam lies within an El Niño-Southern Oscillation (ENSO) core region, which experiences interannual variations of rainfall and drought-like conditions in years following El Niño events. Maximum annual temperatures on Guam during El Niño periods tend to be cooler than average when compared to non El Niño periods (NOAA PIFSC-CRED, unpub. data).

A variety of reef types are represented on Guam, including fringing reefs, patch reefs, submerged reefs, offshore banks and barrier reefs. Fringing reefs are the predominant reef type, extending around much of the island. The shallow (0-2 m) reef flat platform varies in width from tens of meters along some of the windward areas, to over 781 m in Pago Bay (Randall and Eldredge, 1976). The combined area of coral reef and lagoon is approximately 108 km$^2$ in nearshore waters between 0-5.5 m (0-3 nmi), and an additional 110 km$^2$ in federal waters greater than 3 nmi offshore (Hunter, 1995; Burdick, 2006)*. Mangrove growth on Guam is limited to Apra Harbor, which hosts the largest and most developed mangrove forest in the Mariana Islands (approximately 70 ha), and two smaller areas in the southern villages of Merizo and Inarajan. Over 5,100 marine species have been identified from Guam's coastal waters, including over 1,000 nearshore fish species and over 300 species of scleractinian coral (Paulay, 2003; Porter et al., 2005). Guam lies relatively close to the Indo-Pacific center of coral reef biodiversity (Veron, 2000) and possesses one of the most species-rich marine ecosystems among U.S. jurisdictions.

Guam's reef resources are both economically and culturally important, providing numerous goods and services for the residents of Guam, including cultural and traditional use, tourism, recreation, fisheries, and shoreline and infrastructure protection. A recent economic valuation study estimated that the coral reef resources of Guam are valued at approximately $127 million per year (van Beukering et al., 2007). The aesthetic appeal of the reefs and the protection that they

---

*The revised and substantially larger estimate for the total area of nearshore coral reef and lagoon area (compared to the 69 km$^2$ figure reported in Porter et al., 2005) was derived from a recent coastal mapping project conducted by the University of Guam Marine Laboratory (Burdick, 2006). Also note that Rohmann et al. (2005) reported a value of 273 km$^2$ for the area of potential coral reef habitat up to a depth of 183 m (100 fathoms) within the Exclusive Economic Zone (including offshore banks), with 202.8 km$^2$ associated with the island of Guam directly.

1. Guam Coastal Management Program
2. NOAA Fisheries, Pacific Islands Regional Office
3. NOAA Fisheries, Pacific Islands Fisheries Science Center, Coral Reef Ecosystem Division
4. Joint Institute for Marine and Atmospheric Research
5. Guam Environmental Protection Agency
6. University of Guam Marine Laboratory
7. The Nature Conservancy
8. U.S. Fish and Wildlife Service, Pacific Islands Office

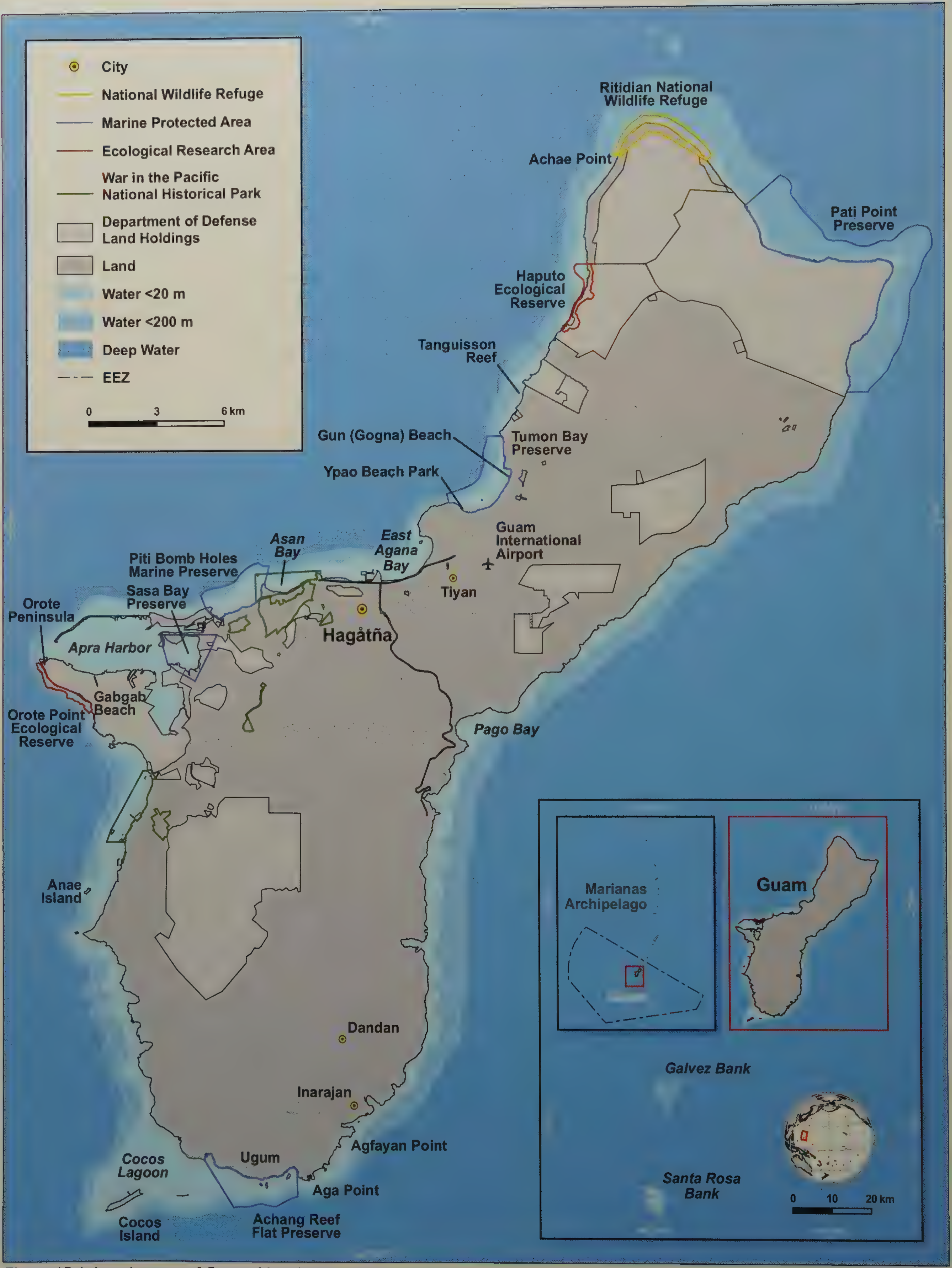

City
National Wildlife Refuge
Marine Protected Area
Ecological Research Area
War in the Pacific National Historical Park
Department of Defense Land Holdings
Land
Water <20 m
Water <200 m
Deep Water
EEZ
0
3
6 km
Ritidian National Wildlife Refuge
Achae Point
Pati Point Preserve
Haputo Ecological Reserve
Tanguisson Reef
Gun (Gogna) Beach
Tumon Bay Preserve
Ypao Beach Park
Guam International Airport
East Agana Bay
Asan Bay
Piti Bomb Holes Marine Preserve
Sasa Bay Preserve
Orote Peninsula
Tiyan
Hagåtña
Apra Harbor
Gabgab Beach
Orote Point Ecological Reserve
Pago Bay
Anae Island
Dandan
Inarajan
Agfayan Point
Cocos Lagoon
Ugum
Aga Point
Cocos Island
Achang Reef Flat Preserve
Marianas Archipelago
Guam
Galvez Bank
Santa Rosa Bank
0
10
20 km

Figure 15.1. Locator map of Guam. Map: K. Buja.

provide for inshore recreational activities help make Guam a popular tourist destination for over one million Asian tourists each year. A recent study that evaluated the contribution of tourism to Guam's overall economy concluded that the tourism industry accounts for 20% of Guam's GDP (32% of non-governmental GDP) and provides over 15,000 direct and indirect jobs (Pike, 2007).

Traditionally, coral reef fishery resources formed a substantial part of the local Chamorro community's diet which included finfish, invertebrates and sea turtles (Amesbury and Hunter-Anderson, 2003). Albeit to a lesser extent than in the past, residents of Guam still use the marine environment for fishing as well as for recreational activities. Despite depleted fish stocks and external influences, fishing is still a popular activity on Guam. Rather than a source of cash or a means of subsistence, fishing activities on Guam's reefs primarily serve as a way to strengthen social bonds and as a source of enjoyment (van Beukering et al., 2007). Many of the residents from other islands in Micronesia continue to include reef fish as a staple part of their diet (Amesbury and Hunter-Anderson, 2003). Sea cucumbers, sea urchins, a variety of crustaceans, molluscs and marine algae are also eaten locally.

In response to declining reef fish stocks, approximately 15.5% (36.1 km$^2$) of Guam's nearshore (<183 m) waters was set aside in five locally-established Marine Preserves in 1997 (Figure 15.1). The preserves, which include the Tumon Bay, Piti Bomb Holes, Sasa Bay, Achang Reef Flat and Pati Point Marine Preserves, protect a variety of habitats. Enforcement of fishing restrictions within these areas began in 2001. The preserves are complemented by the War in the Pacific National Historical Park (WAPA), the Ritidian National Wildlife Refuge, the Orote and Haputo Ecological Reserve Areas and the Guam Territorial Seashore Park, although these areas currently possess only limited management and enforcement.

The health of Guam's coral reefs varies considerably around the island, depending on a variety of factors including geology, human population density, level of coastal development, level and types of uses of marine resources, oceanic circulation patterns, coral predator outbreaks and natural disasters such as typhoons and earthquakes (Figure 15.2). Similar to the decline in health of reefs across the Indo-Pacific (Bruno and Selig, 2007), the vitality of many of Guam's reefs has declined over the past 40 years. The average live coral cover on the fore reef slopes was approximately 50% in the 1960s (Randall, 1971), but by the 1990s had dwindled to less than 25% live coral cover, with only a few sites having over 50% live cover (Birkeland, 1997).

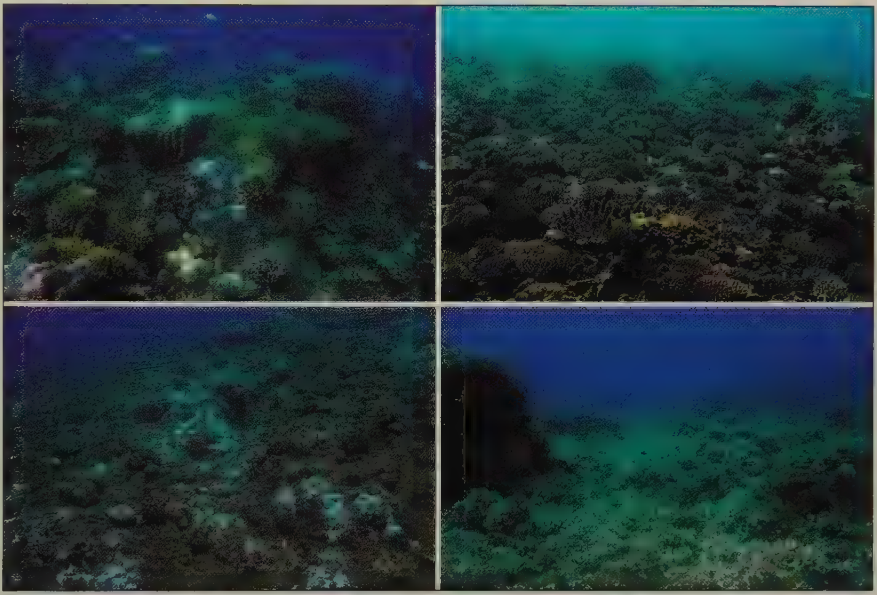


*Figure 15.2. Clockwise from upper left: extensive coral growth near Gabgab Beach in Apra Harbor; an* Acropora*-dominated reef community on a shallow fore reef terrace along the southeast coast; a reef community near Anae Island, on the southwest coast, that is heavily impacted by regular sedimentation events; and an extensive macroalgal bloom (*Padina *sp.) near Apaca Point along the southwestern coast. Photos: D. Burdick.*

In the past, Guam's reefs have recovered after drastic declines. For example, an outbreak of the crown-of-thorns sea star (*Acanthaster planci*; COTS) in the early 1970s reduced coral cover in some areas from 50-60% to less than 1%. Twelve years later, greater than 60% live coral cover was recorded in these areas (Colgan, 1987). However, continued degradation of water quality, COTS outbreaks, low abundance of target fish species and other persistent stressors currently affecting Guam's reefs make the reefs less resilient. A particularly distressing indicator of declining reef resilience is the marked decrease in rates of coral recruitment in the last few decades (Birkeland et al., 1981; Birkeland, 1997; Neudecker, 1981; Porter et al., 2005). A recent two-year study conducted by the National Park Service in Asan Bay found rates of coral recruitment similar to the low rates reported in previous studies, with an average of only 0.02 recruits per PVC plate (Minton et al., in prep; see p.18, this report). The decrease in resilience to major stress events is of particular concern when the anticipated impacts of global climate change, such as the increased incidence and severity of bleaching events (Hoegh-Guldberg, 1999), ocean acidification (Kleypas et al., 1999; Meehl et al., 2007) and an increase in the strength of cyclones (Emanuel, 2005; Meehl et al., 2007) are considered.

## ENVIRONMENTAL AND ANTHROPOGENIC STRESSORS

### Climate Change and Coral Bleaching

The reefs of Guam have been spared from severe and widespread coral mortality associated with large-scale bleaching events, but observations in 2006 and 2007 suggest that bleaching events in Guam's reefs may become more frequent and severe in the coming decades. The first large-scale bleaching event reported in Guam since the establishment of the University of Guam Marine Laboratory (UOGML) in 1970, was an event in 1994, with another event reported in 1996 (Paulay and Benayahu, 1999). The bleaching in 1996 was believed to have been more severe than in 1994, but a detailed record is not available. It is generally held that neither of these events resulted in significant coral mortality. Paulay and Benayahu (1999) reported that these events were not related to elevated water temperatures, but a recent examination of satellite-derived sea surface temperature (SST) measurements suggests that sustained, higher than average water temperatures may have played a role.

After nearly a decade without reports of large-scale bleaching, coral bleaching was observed in September and October 2006 and August and September 2007 (Figure 15.3). Both the 2006 and 2007 events appear to have been associated with above-average SSTs and coincided with bleaching watches/warnings issued by the National Oceanic and Atmospheric Administration (NOAA) Coral Watch Program based on satellite measurements of sea surface temperature. During both events, bleaching was observed among numerous species on the reef flat and reef front to a depth of 7 m at several sites around the island (D. Burdick, pers. obs.). The widespread distribution of the 2007 bleaching event was confirmed with observations from an aerial survey carried out in August 2007 (D. Burdick, pers. obs.).

The effect of the 2006 and 2007 events on Guam's reefs was difficult to properly assess, as limited resources and reef access resulted in only a handful of observations and few quantitative data. A survey of *Pocillopora verrucosa* colonies at Anae Island, off Guam's southwest coast, found that 67% of colonies at 1-3 m water depth were pale or full or partially bleached in September 2006 (Chau, unpub. data). Of a total 36 tagged *P. verrucosa* colonies, all appeared to have fully or partially recovered after more than three months. In contrast, about 60% of all coral species surveyed in October 2006 along a single transect on the reef margin in the Tumon Bay Marine Preserve (TBMP) exhibited partial or full mortality (Brown, 2007). Surveys of an arborescent *Acropora*-dominated coral community in Tumon Bay in August 2007 indicated that approximately 60% of the live coral and >90% of the *Acropora* species along five 25 m transects exhibited paling or partial bleaching (Figure 15.3; Brown and Burdick, unpub. data). Because this nearly monotypic, *Acropora*-dominated coral community is not common on Guam, observed bleaching rates are not representative of Guam's reefs. A qualitative survey of the north side of Cetti Bay indicated that at least eight scleractinian coral genera were affected to a depth of about 7 m (Brown, unpub. data).

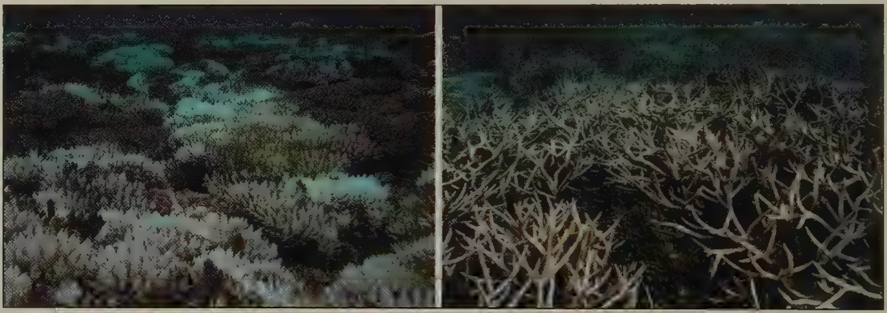


*Figure 15.3. Bleached Acropora colonies on the reef margin at Gun Beach in October 2006 (left) and on the reef flat platform at Ypao Beach in August 2007 (right). Both sites are located within the Tumon Bay Marine Preserve (TBMP). Turf algae are apparent on some of colonies in the photo on the left, indicating at least partial mortality. Photos: D. Burdick.*

### Diseases

Coral disease surveys were conducted by the UOGML in 2006 and 2007 to establish baseline levels of coral disease. To date, 10 reefs have been surveyed for benthic composition, coral disease prevalence, and host species range; the survey methodology is described in the Benthic Habitats section. Diseases and syndromes affecting Guam reefs are largely similar to those reported elsewhere in the region (Raymundo et al., 2005; Willis et al., 2004), with the addition of a potential syndrome that has not been characterized or described elsewhere.

Disease prevalence was highly variable within and between sites and did not show a strong relationship with live hard coral cover (Figure 15.4). Of the 10 surveyed

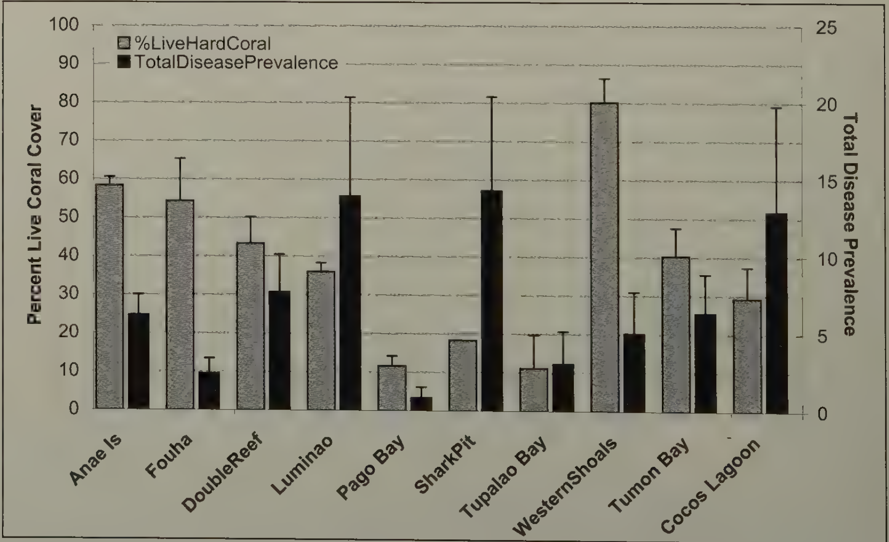


*Figure 15.4. Live hard coral cover and total disease prevalence for each survey site (mean ± SE; n=3-4 transects/site).* ***NOTE:*** *the percent live hard coral and total disease prevalence values are measured along different y-axes. Source: L. Raymundo, unpub. data.*

reefs around Guam, three exhibited total prevalence values >10% (Luminao, Cocos Lagoon and Shark Pit Rock). While a baseline figure for total disease prevalence has not been established, using published literature as a guideline, it is reasonable to suggest that prevalence figures greater than 10% can be considered high and potentially problematic. Therefore, it appears from this initial census that disease may be causing at least partial mortality in a significant number of colonies in these reefs.

Of the diseases reported from the Indo-Pacific region, white syndrome (Figure 15.5A) appears to be the most prevalent (observed in nine out of 10 sites) and the source of greatest tissue mortality. Black band disease, the only documented circumtropical disease, is rare on Guam reefs, and has been observed primarily on massive *Porites* at Luminao Reef. The ciliate causal agent of brown band disease (Figure 15.5B) was identified via microscopy in several species of *Acropora* from some reefs, including Tumon Bay and Luminao Reef. Growth anomalies of several distinct types, which were the first diseases to be described from Guam (Cheney, 1977), are more common, particularly on massive *Porites* (Figure 15.5C). Ulcerative white spots (Figure 15.5D), first described from the Philippines (Raymundo et al., 2003), have also been observed in Guam, though at very low prevalence.

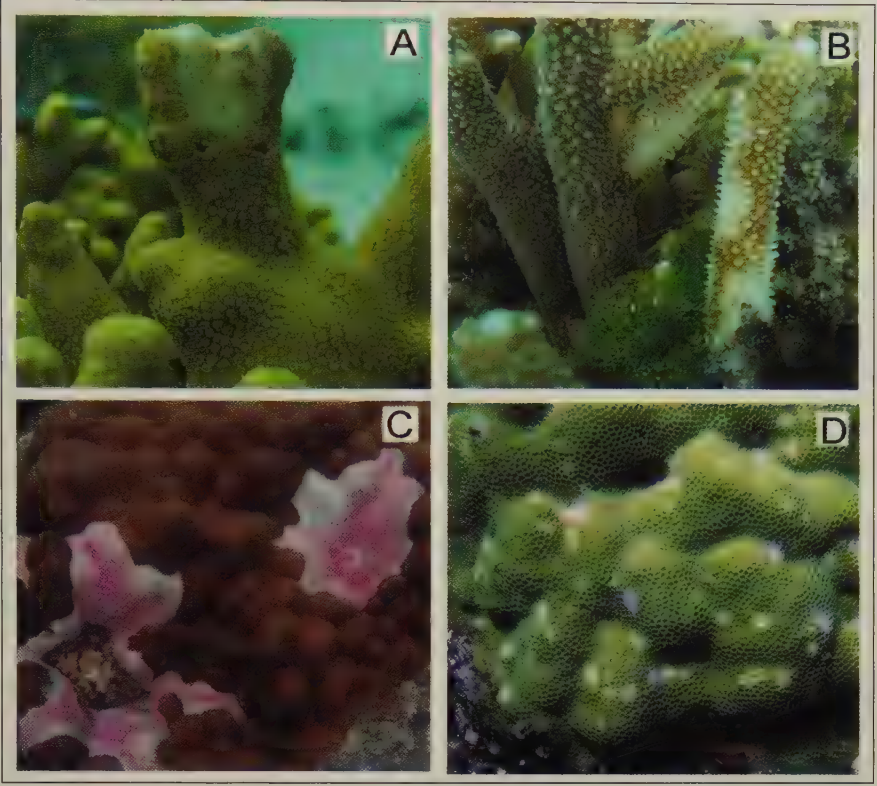


*Figure 15.5. Coral diseases recorded from Guam reefs. A) white syndrome on* Porites *(Luminao Reef); B) brown band disease on* Acropora *(Luminao Reef); C) growth anomaly on* Porites *(Double Reef); D) ulcerative white spots on massive* Porites *(Pago Bay). Photos: L. Raymundo, University of Guam Marine Lab (UOGML).*

## Tropical Storms

Guam is in a highly active region of the western Pacific for tropical storms, and has been hit by four typhoons with sustained winds greater than 150 mph since 1994. Although Guam has been spared a direct hit by a typhoon-strength storm since Super Typhoon Pongsona (December 2002), Typhoon Tingting brought high winds and record rainfall in June 2004 (Figure 15.6). While several other tropical cyclones passed close enough to Guam to influence its weather in the last three years, Guam did not experience any major storms in 2005 or 2006.

Tropical storm systems typically occur in the more humid summer months and can develop rapidly. During El Niño Southern Oscillation (ENSO) years, increased SSTs move the cyclone breeding ground toward the central Pacific, increasing the number of typhoons generated east of the Mariana Islands (Lander, 2004; Minton and Palmer, 2006). Large offshore waves associated with storm-driven winds can cause physical damage to the reef. Storm surge and wave inundation can increase local sea levels by over 40% of the offshore significant wave height (Vetter, 2007). Large influxes of rain-

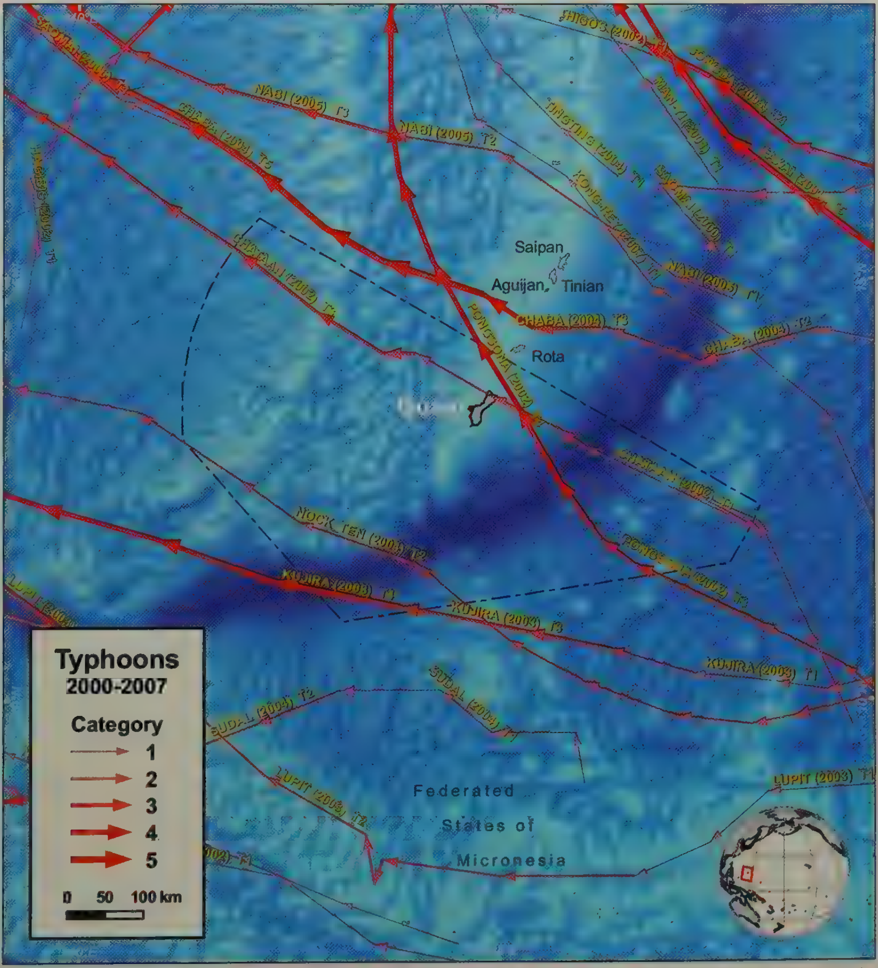

HIGOS (2002)
NABI (2005) T3
NABI (2005) T2
CHABA (2004) T5
TINGTING (2004) T1
KONG-REY (2007) T1
Saipan
Aguijan
Tinian
NABI (2005) T1
CHATAAN (2002) T2
CHABA (2004) T3
PONGSONA (2002)
Rota
CHABA (2004) T2
Guam
NOCK-TEN (2004) T2
KUJIRA (2003) T1
KUJIRA (2003) T3
PONGSONA (2002) T3
KUJIRA (2003) T1
SUDAL (2004) T2
SUDAL (2004)
LUPIT (2003) T2
LUPIT (2003) T1
Federated States of Micronesia
Typhoons
2000-2007
Category
1
2
3
4
5
0 50 100 km

*Figure 15.6. Path and intensity of tropical cyclones passing near Guam, 2000-2007. Map: K. Buja. Source: http://weather.unisys.com/hurricane/.*

water laden with sediments, nutrients, debris and other anthropogenic inputs can be detrimental to coral reef ecosystems (Jokiel, 1993).

## Coastal Development and Runoff

Although most development between 2004 and 2007 has involved residential or other small-scale construction, several major development projects have started recently or are planned for the near future to accommodate the growing tourism sector and planned military expansion. Development associated with the incoming military personnel, their dependents, and support staff, such as construction of military facilities and off-base housing developments and road-building activities, has the potential to negatively impact coastal water quality.

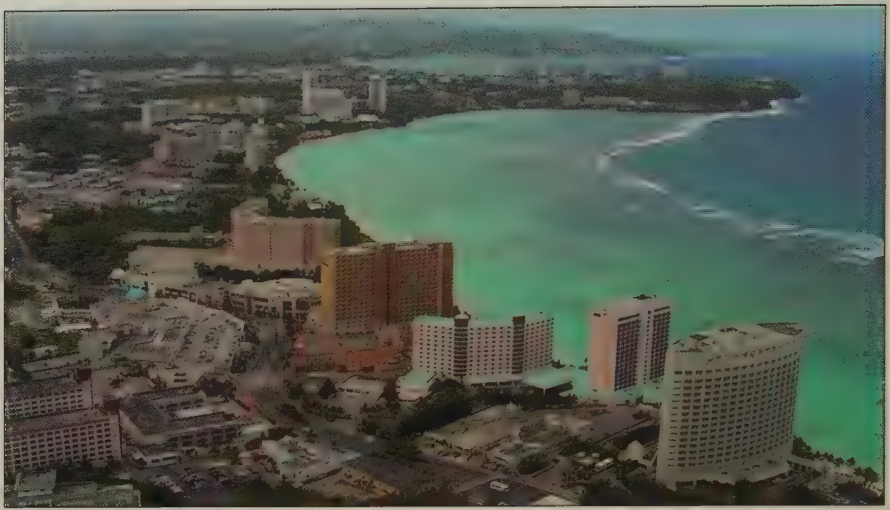


Figure 15.7. High density development along the TBMP. Photo: J. Jocson.

Hotel Okura, situated along the coast of the TBMP (Figure 15.7), is currently re-developing a section of the coastline for luxury bungalows. Another major development along the preserve is an 8.7 ha development planned for the Gun Beach area, a popular recreational site for both residents and tourists. The infrastructure planned to accommodate this development will likely encourage nearby land owners to develop in this area, which contains some of the last remaining undeveloped land along the bay. Construction activities, the reduction in shoreline vegetation, and the application of fertilizers and pesticides associated with these developments are likely to impact coastal water quality.

The U.S. Navy has recently undertaken several projects in Apra Harbor that will impact coral reef habitat, with several additional projects planned for the near future. The Alpha/Bravo Wharves' Improvements Project, scheduled for 2007, will involve the removal of 2.9 ha (7.1 acres) of coral reef habitat (Commander Navy Region Marianas, 2006). The military is also expanding the ammunition Kilo wharf, located on Orote Peninsula, in order to accommodate a new class of ammunition ships (Commander Navy Region Marianas, 2007). The Kilo wharf expansion will involve the removal of 1.92 ha (4.75 acres) of coral reef habitat, with sedimentation impacts from dredging operations potentially affecting between 0.68 and 6.02 ha (1.69 and 14.88 acres) of additional coral reef and associated habitat. Of particular concern is the U.S. Navy's proposal to enhance infrastructure and improve waterfront facilities to support transient nuclear aircraft carrier berthing. One of the sites favored for the proposed carrier berthing is at Polaris Point, in Apra Harbor (Helber, Hastert and Fee Planners, 2006). In addition to the impacts to reef habitat during construction of the new 400 m wharf, dredging of nearby shoals popular with tourists and fishermen may be required to provide space for an adequate turning basin.

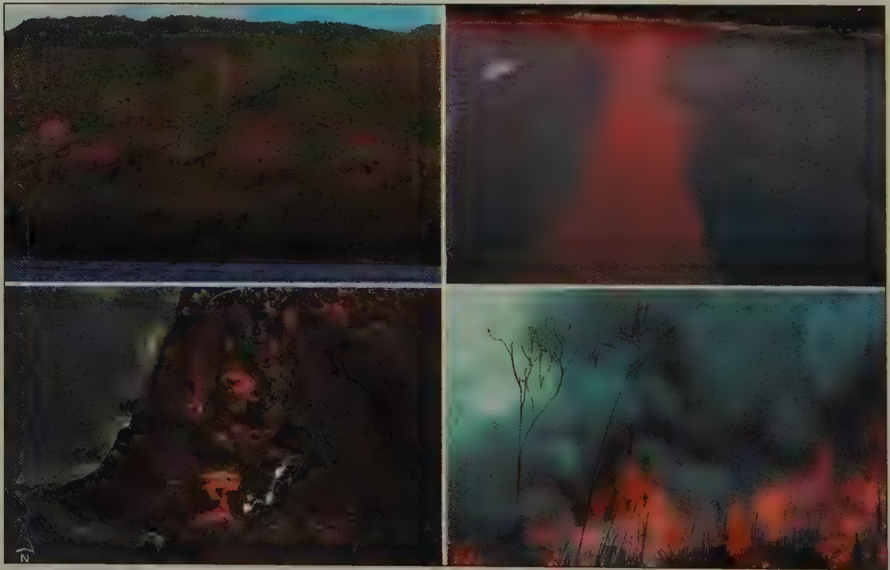


Figure 15.8. Clockwise from top-left: view of exposed soil along southwestern coast of Guam; concentrated plume of clay-like soils deposited into coastal waters near same area; a fire burning through a hillside in southern Guam; and a Quickbird satellite image from 2005 depicting large expanses of exposed soil and recently-burned areas in southwestern Guam. Quickbird satellite image provided by DigitalGlobe. Photos: D. Burdick and Guam FSRD.

Sedimentation of nearshore habitats, primarily a result of severe upland erosion, continues to be one of the most significant threats to Guam's reefs (Figure 15.8). Sedimentation is most prevalent in southern Guam, where steep slopes, underlying volcanic rock, barren areas and areas with compromised vegetation contribute large quantities of the mostly lateritic, clay-like soils to coastal waters. According to one estimate, the sediment yield of unvegetated "badlands" is more than 20 times that of ravine forests (243 tons/acre/yr versus 12 tons/acre/yr), while savannah grasslands, which also cover large areas of southern Guam, produce more than 2.5 times as much sediment as ravine forests (U.S. Dept. of Agriculture, NRCS, 1995). The excess sediment flows into coastal waters, where it combines with organic matter in sea water to form "marine snow," falling to the seafloor and smothering corals and other sessile organisms (Wolanski et al., 2003). Sediment, along with excess nutrients and freshwater, can also interfere with or inhibit coral gamete production, release, and viability, and larval survival, settlement and recruitment (Hodgson, 1990; Tomascik, 1991; Wittenberg and Hunte, 1992; Ward and Harrison, 1997; 2000; Gilmour, 1999). While it is generally held that Guam's southern reefs have evolved under a regime characterized by a larger sediment loads than at northern reefs, an increase in destructive anthropogenic activities, including wildland arson, clearing and grading of forested land, inappropriate road construction methods and recreational off-road vehicle use, as well as grazing by feral ungulates, have accelerated rates of sedimentation and appear to have exceeded the sediment tolerance of coral communities in these areas, resulting in highly degraded reef systems. In Fouha Bay, for example, more than 100 coral species were found along transects in the southern part of the bay in 1978, but less than 50 were found in 2003 (Richmond et al., 2007), demonstrating a significant loss in species richness.

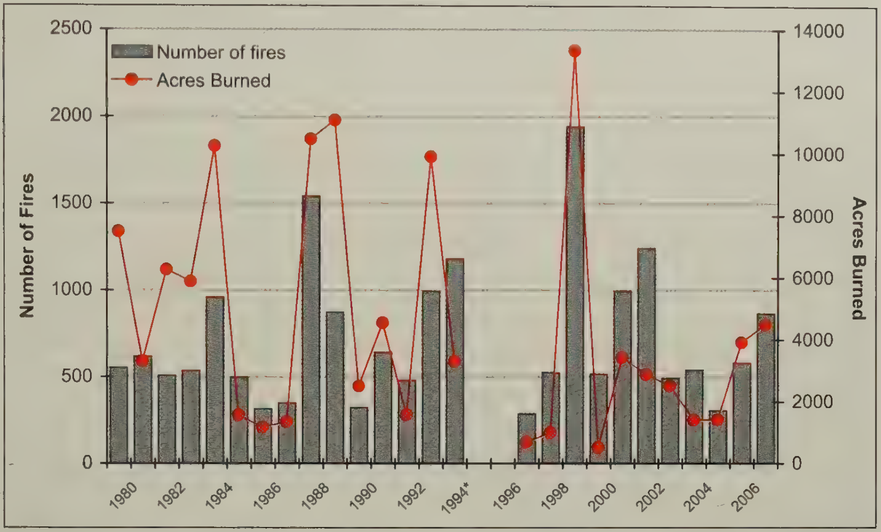


*Figure 15.9. Frequency (number of fires/year) and extent (acres burned) of wildfires in Guam from 1979-2006. Note the steep increase in the number and extent of fires during El Niño periods (1982/1983, 1987/1988, 1992/1993 and 1997/1998). Asterisk (*) indicates that wildfire data were not available (1994 and 1995). Source: Guam FSRD, unpub. data.*

Wildfires set by poachers are believed to be the main cause of badlands development and persistence (Minton, 2005). Despite being illegal, intentionally-set fires continue to burn vast areas of southern Guam. According to figures from the Department of Agriculture's Forestry and Soil Resources Division (FSRD), an average of over 700 fires have been reported annually between 1979 and 2006, burning over 46.5 ha (115,000 acres) during this period (Figure 15.9). The devastating effects of illegally-set wildfires in southern Guam are exacerbated by the drought-like conditions associated with El Niño events.

According to the Guam Department of Agriculture, there are approximately 1,300 farms on Guam; about 200 are considered commercial farms, while the remainder are comprised of small ventures of less than a few acres (Borja, pers. comm.). There are little available data on the quantity and types of fertilizers, pesticides and herbicides used on these farms. The use of fertilizers and pesticides on Guam's nine civilian golf courses, which occupy a total of approximately 566.6 ha (1,400 acres), is regulated and monitored by the Guam Environmental Protection Agency (Guam EPA) under approved turf management plans. Still, there is no regular monitoring of nearshore water quality and benthic habitat or associated biological community health adjacent to courses situated near the coast.

## Coastal Pollution

The primary pollutants to most waters around Guam – and specifically to recreational beaches – are microbial organisms, petroleum hydrocarbons and sediment. The Guam EPA locally administers the Water Quality Certification permits (Clean Water Act Section 401) and coordinates the National Pollutant Discharge Elimination System (NPDES) permits for the U.S. EPA. Presently there are 19 active NPDES permits on Guam (see Porter et al., 2005 for a list of permitted facilities) to regulate discharges of treated wastewater from the sewage treatment plants (STP), thermal effluent from the Guam Power Authority power plants, and a number of other discharges which could contain minor amounts of oil and other toxic or biological materials. The guidelines for effluent limitations are based on the Guam water quality standards which underwent major revision in 2001 (Guam EPA, 2001). All permittees are routinely monitored by Guam EPA staff to verify compliance with applicable permit requirements and compliance schedules. The new 2001 Guam water quality standards were applied when the five-year NPDES permits were renewed in 2006, but monitoring before that time utilized the standards in place when they were issued. Violations reported in the 2005 and 2006 NPDES monitoring reports are summarized in Table 15.1.

Three of the island's STP outfall pipes continue to discharge within 200 m of the shallow reef crest, in depths of 20-25 m and in areas where corals are found. Stormwater leakage into aging sewer lines during heavy rains forces the sewage treatment plants to divert untreated wastewater directly into the ocean outfall pipes. Additionally, since Super Typhoon Pongsona impacted Guam in 2003, effluent from the Hagåtña STP has been partly discharging into a shallow coral reef area due to a break in the outfall line.

Nonpoint source pollutants in the north often infiltrates basal groundwater, which discharges into springs along the seashore and subtidally on the reefs. Pollutants include nutrients from septic tank systems, sewage spills, and livestock and agricultural areas, as well as chemical discharge from urban runoff, farms and illegal dumping. Several studies have detected chemicals from the Northern Guam Aquifer in spring water discharges to Tumon Bay that exceeded Guam EPA water quality standards (PCR Environmental, Inc., 2002a, 2002b, 2002c), while another study determined that stormwater draining from the Guam International Airport and surrounding industrial areas entered Tumon Bay and East Agana

*Table 15.1. Number of quarters between 2005 and 2006 in which allowable pollutant limits were exceeded at NPDES-permitted facilities. NPDES facilities that did not register violations during this period are not included in this list. Source: Guam Environmental Protection Agency Guam EPA.*

| NPDES-PERMITTED FACILITY | POLLUTANT | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | BOD | SuS | SeS | EC | EN | FC | $PO_4$-P | $NO_3$-N | TB | N | Fe | Cu | Ni | $NO_3$ | BZ | Pb | Zn | Al | pH | Mn | P | CR |
| Agana STP | 5 | 8 | 8 | | | | | | | | | | | | | | | | | | | |
| Baza Gardens STP | 6 | 3 | | 8 | | | 8 | 3 | 8 | 1 | | | | 4 | | | | | | | | |
| Agat/Santa Rita STP | 7 | 7 | | | 8 | 8 | | | | | | 8 | 1 | | | | 5 | 8 | | | | |
| Umatac/Merizo STP | 1 | 1 | | 1 | 1 | | 1 | | 1 | | | | | | | | | | | | | |
| Northern District STP | 4 | 8 | 6 | | | | | | | | | | | | | | | | | | | |
| Tanguisson Power Plant | | 2 | | | | | | | | 8 | 8 | 7 | | | | | | | | | | |
| Piti Tank Farm | | | | | | | | | | | | | | | 2 | | | | | | | |
| South Pacific Petroleum | | | | | | | | | | | | | | | 1 | 1 | | | | | | |
| Guam International Airport | | | | | | | 3 | | | | | | | | | | | | 1 | | | |
| Naval Station STP | 1 | 6 | | | 3 | 1 | | | 1 | | | 8 | 7 | | | | | 8 | | 1 | | |
| Continental Air Micronesia | | | | | | | | | | | | | | | | 2 | | | | | 6 | |
| Leo Palace STP | | | | | | | | | | | | | | | | | | | | | | 1 |
| Mobil Cabras Terminal | | | | | | | | | | | | | | | | 1 | | | 3 | | | |
| Dry Dock (AFDM8) | | 2 | | | | | | | | | | 2 | | | | | | | | | | |

**Pollutant**: BOD = Biochemical oxygen demand; SuS = Suspended Solids; SeS = Settleable Solids; EC = *E. coli*; EN = *Enterococi*; FC = Fecal coliform; $PO_4$-P = Orthophosphate; $NO_3$-N = Nitrate-Nitrogen; TB = Turbidity; N = Nitrogen; Fe = Iron; Cu = Copper; Ni = Nickel; $NO_3$ = Nitrate; BZ = Benzene; Pb = Lead; Zn = Zinc; Al = Aluminum; pH = pH; Mn = Manganese; P = Phosphorous; CR = Chlorine Residual

Bay through the aquifer within four and 17 days, respectively (Moran, 2002). Previous studies have also found moderate enrichment of contaminants, including polychlorinated biphenyls (PCBs) and polycyclic aromatic hydrocarbons (PAHs) in newly formed marine sediments and associated food chains in the four main harbor areas of Guam (Denton, et al., 1997; Denton et al., 1999; see Porter et al. 2005).

The U.S. Navy has recently completed restoration (under the Comprehensive Environmental Response, Compensation, and Liability Act and the Resource Conservation and Recovery Act) of five sites contaminated with toxic chemicals from operations dating to World War II (WWII) on Guam and continues to assess and restore another 15 sites. Most of these sites are on or near shorelines. In 2001, it was determined that PCBs had entered the food chain offshore from the Orote Landfill site and off Gabgab Beach. The source of the PCBs has yet to be identified, but PCBs and other chemicals present in buried material at the landfill make the site a potential source, even though it has been capped and contained by a restoration project costing over $15 million (M. Wolfram, pers. comm.). Monitoring wells and other sampling techniques undertaken in 2006 seemed to indicate that other sources of the contamination may be upstream of the landfill (Commander Navy Regional Marianas, 2005). Seafood monitoring has detected PCBs in deep and shallow water reef fishes in the Philippine Sea off Orote Point, and the public has been advised on the danger of consuming seafood from this area (Agency for Toxic Substances and Disease Registry, 2002). Investigations into the former Coast Guard Long Range Navigation station on Cocos Island suggested that the lagoon may have been contaminated by PCBs as a result of dumping activity that occurred during the station's active use between 1944 and 1963. Sediment sampling of the intertidal zone has not yielded any detectable toxins, but a number of fish species near the site exhibited PCB concentrations above the recommended limit for subsistence fishers (Element Environmental, 2006). The Coast Guard is currently engaged in site remediation and is considering additional testing for biota.

Guam's only public dump, which is located in the village of Ordot, has been utilized for over fifty years. The site has been a source of leachate that could impact Pago Bay reefs via the Lonfit/Pago Watershed (Denton, et. al., 2005a). Baseline monitoring of the Pago Bay marine environment completed in 2006 by the University of Guam's Water and Environmental Research Institute (WERI), however, indicates that the pollutants are not having significant impacts on biological communities in the bay (Denton et al. 2006). A Federal Court Consent Decree with the Government of Guam required the closing of this dump by September 2007, but this date could not be met.

In 2000-2001, researchers from WERI investigated the potential causes of intertidal blooms of the filamentous green algae, *Enteromorpha clathrata*, in Tumon Bay (Denton et al., 2005b). Measurements of nitrogen, phosphorous, and silica levels from nearshore water samples and from emergent groundwater seeps and springs at intertidal sites in Tumon Bay indicated that nitrogen was abundant in this region of the bay, while phosphorus levels were frequently limiting. The data also indicated that the northern freshwater aquifer was not the only source of phosphorus for the bay, suggesting that small anthropogenic inputs of phosphorus, such as from fertilizers used on hotel grounds, could influence the abundance and distribution of *E. clathrata* in the bay.

## Tourism and Recreation

The number of visitors to Guam grew from 1.16 million visitors in 2004 to 1.21 million in 2006, indicating continued growth after a 10-year low of approximately 910,000 in 2003 (Guam Visitors Bureau, 2006). SCUBA diving, snorkeling and related activities continue to be very popular for both tourists and residents. According to a recent coral reef economic valuation study conducted on Guam, an estimated 300,000 dives are performed on Guam each year (van Beukering et al., 2007). Official Pacific Association of Dive Industry statistics cited in this study indicate that around 6,000 open water certifications were provided in 2004; the number of certifications provided by other organizations is not known. The number of divers and snorkelers visiting Guam's reefs will likely increase significantly with the additional military personnel, their dependents and others associated with the military expansion.

Overuse and misuse of certain high-profile reef areas for recreational activities continues to be a concern (Figure 15.10). Of particular concern is the extraordinary number of divers, snorkelers, swimmers, and Sea-Walker and SCUBA customers that continue to utilize relatively small areas in the Piti Bomb Holes and TBMP. The number of divers in the Piti Bomb Holes Marine Preserve increased considerably after access to another popular beginner-diver site in Apra Harbor was restricted and access to a third site was eliminated by a road fortification project. An estimated 50-200 dives occur daily within a popular 0.25 ha (0.6 acre) "bomb hole" (i.e., solution hole) in the Piti Bomb Holes Marine Preserve (Brown, pers. obs.). Even a conservative estimate based on these observations suggests that the number of dives that occur at this small site each year (>18,000) vastly exceeds the 4,000-6,000 diver per year threshold value above which coral cover loss and coral colony damage levels may increase rapidly (Hawkins and Roberts, 1997; Hawkins et al., 1999).

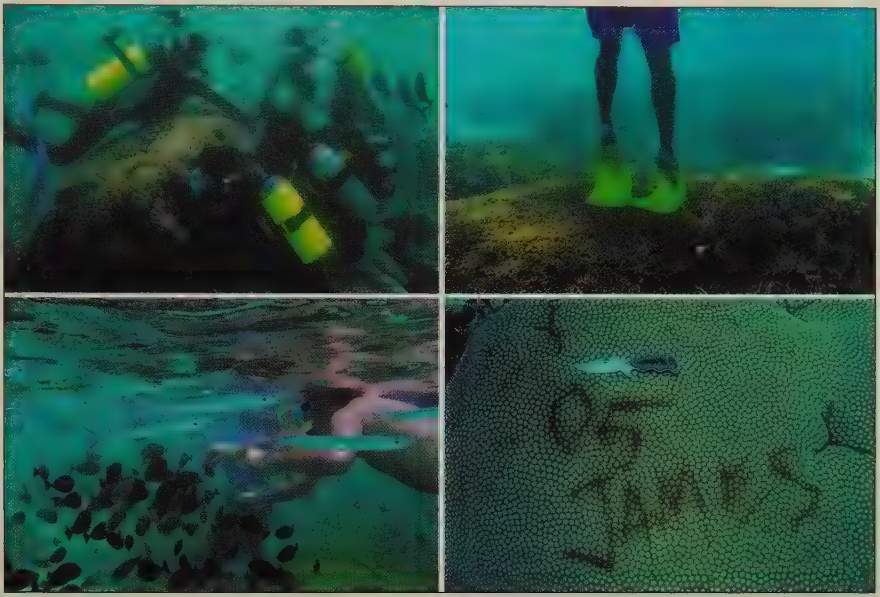


*Figure 15.10. Clockwise from upper left: a dive guide instructs clients to grab a large* Porites *sp. colony in the Piti Bomb Holes Marine Preserve; a snorkeling guide observes his clients while standing atop a colony of* Porites cylindrica *at Ypao Beach in the TBMP; "reef graffiti" carved into a large* Diploastrea heliopora *colony on Hap's Reef, a popular dive site off the southwestern coast of Guam; and a snorkeler feeding fish at Ypao Beach in the TBMP. Photos: D. Burdick.*

Most of the divers at easily accessible, shallow, protected sites are open water students or resort divers. Reef habitat at popular dive sites is often adversely impacted when numerous inexperienced divers visit the site within a short period. Broken pieces of coral and colonies damaged by kicking, grabbing and standing are often observed in these areas. Other impacts, such as trampling of coral and other benthic organisms, increased turbidity and alterations of fish behavior from fish feeding are also regularly observed. These behaviors and associated damage are also routinely observed at popular boat diving sites, such as Blue Hole, Hap's Reef, Finger Reef and Western Shoals. Many operators display a lack of awareness or disregard for their impact to the reef and regularly encourage their clients to grab or sit on coral colonies and feed fish. This behavior has been documented by resource agency personnel at several sites (Figure 15.10).

The operation of motorized personal watercraft (PWC) is restricted to four reef flat/lagoon areas around Guam under the Recreational Water Use Master Plan, including limited areas within East Agana Bay, Apra Harbor, Cocos Lagoon and Tumon Bay, to reduce conflict with other water-based activities. PWC use is not restricted beyond the reef margin. Although these craft are loud, known to leak fuel and have the potential to scour seagrass beds and corals, the results of a 2006 study by PCR Environmental, Inc., of the direct, cumulative and secondary impacts of PWCs in heavily used East Agana Bay showed no significant effect on water quality or biological communities (PCR Environmental, Inc., 2006).

Mechanical beach cleaning equipment is still utilized four or five times a week by the Guam Visitor's Bureau (GVB) to remove trash and other material from Tumon Bay and East Agana Bay beaches. There is concern about the impact of this activity on the stability of the beach and on the health of intertidal biota and associated biological communities. Previous recommendations, such as requiring contractors to shake out as much sand and dead coral as possible from algae and place the material back onto the beach, are rarely followed. Piles of dead coral and sand left on the beach along with the large amounts of beach material brought to the Ordot dump serve as evidence. The recommendation to implement an adopt-a-beach program, in which hotels pledge to manually rake the algae from beaches on their property, has not yet been carried out. No known beach nourishment projects occurred between 2004 and 2007.

## Fishing

Guam's coral reef fisheries are both economically and culturally important and target a large number of reef fishes and invertebrates. Reef-related fishing methods currently used on Guam include hook and line, cast net (talaya), spear fishing with snorkel and SCUBA, gill net (tekken), surround net, trolling, drag net (chenchulu), hooks and gaffs, jigging, spincasting and bottom fishing. Despite improvement in gear and technology, Guam's fishery catches have declined over the last few decades. A recent re-estimation of small-scale fishery catches for Guam suggests that catches have declined by up to 86% since 1950 (Zeller et al., 2007).

While there is no clear consensus on the cause of this decline, fisheries impacts certainly contribute. This is supported by offshore catch experiments conducted by the Guam Division of Aquatic and Wildlife Resources (DAWR) at three offshore banks that experience different levels of fishing pressure. The data indicated that the number of high level predators decreased with fishing pressure while the number of small groupers increased. Using *Lethrinus rubrioperculatus* as an indicator species, the data also indicate a shift in size frequency with increased fishing pressure (Tibbatts, 2006). Additionally, data from creel surveys performed by DAWR suggest that Guam's fisheries have not recovered from a sharp decline in the 1980s. For a number of methods, including hook and line and cast net, the harvest has continued to decline despite increasing effort. While the catch per unit effort (CPUE) for spear fishing has remained relatively stable, the species composition of the catch has changed over time (Flores, 2006a). *In situ* visual surveys have also indicated that large reef fish are conspicuously absent from many reefs (Paulay et al., 2001; Amesbury et al., 2001; Schroeder et al., 2006).

Two fishing methods used on Guam have raised particular concern: the use of SCUBA and artificial light for spear fishing and the use of monofilament gill nets. These methods have been banned or heavily restricted in most of the region, including the Commonwealth of the Northern Mariana Islands and American Samoa. In Guam, local fisheries biologists suggest that these methods may have led to a boom and bust harvest of large Napoleon wrasse, the depletion of large groupers, a shift from preferred species (large slow-growing fish) to smaller faster growing species and a decrease in the number of other large wrasse, parrotfish, snapper and grouper caught by other methods (Flores, 2006a). Abandoned gill nets also cause physical damage to the reef and DAWR regularly removes nets from nearshore reefs (Figure 15.11).

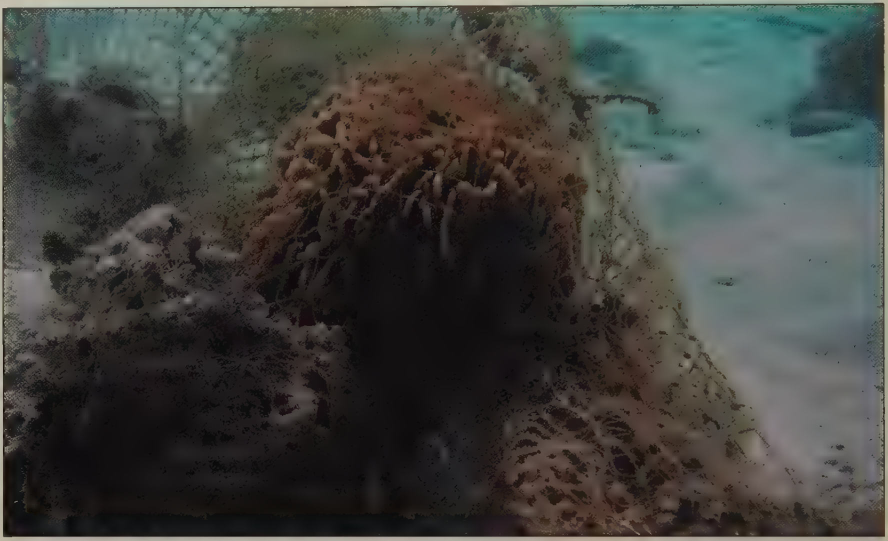


*Figure 15.11. A monofilament gill-net on a coral. Photo: V. Brown.*

To combat the fishery declines, the government of Guam created a system of five marine preserves designed to increase fish stocks by establishing areas where limited or no harvest of marine species is permitted (Figure 15.1). Initial surveys indicate that the fish stocks in the preserves have increased and appear to be working as designed. Unfortunately, the large fish in the preserve areas are targets for fishermen who disregard the marine preserve designation. Guam DAWR law enforcement officers have made more than 140 arrests related to illegal fishing within the preserves since they began enforcing the regulations in January 2001. Arrests are highest in the Tumon Bay and Piti Bomb Holes Marine Preserves, but infractions have been documented in all five of the preserves.

## Trade in Coral and Live Reef Species

Guam does not currently export coral or live reef species, but collection for local use does occur. Guam's corals and live rock are protected by local law (5 Guam Code Annotated Chapter 63). The UGOML is the only entity on the island permitted to harvest coral and live rock. The UOGML's permit only allows harvesting in areas not designated as marine preserves, and all surviving specimens must be returned to the area from which they were harvested. According to the UOGML, 1,067 coral colonies were collected in 2004, 227 in 2005 and 57 in 2006 for research purposes. The majority (>80%) of colonies collected in 2004 and 2005 were colonies of *Leptastrea purpurea* and *Pocillopora damicornis*, both of which are abundant on Guam. Over 50% of the corals collected in 2006 were *L. purpurea*. According to catch records turned in to DAWR, a total of 3,132 fish and invertebrates were collected for aquariums on Guam in 2006. The most frequently caught fish families were damselfish and surgeonfish (Table 15.2). Sea anemones were formerly the most frequently collected invertebrates, but since 2006 have been protected by Public Law 28-107.

## Ships, Boats and Groundings

Guam's Apra Harbor is the largest U.S. deepwater port in the Western Pacific and the busiest port in Micronesia. It contains reefs with some of the highest coral cover on the island. Some of these reef areas may be dredged in the future as their growth impedes ship traffic and naval operations. They are also threatened by anchoring, grounding events and illegal vessel discharges. The harbor is shared by the Port Authority of Guam and the U.S. Navy. According to the Port Authority (http://www.portofguam.com/), the port handled an average of approximately two million tons of cargo a year and serviced an average of approximately 1,600 vessels a year between 2002 and 2006. These vessels are primarily fishing vessels, but also include fuel ships, container ships, tender ships, barges and cruise ships. The U.S. Naval installation is home to a number of naval vessels, including submarines and associated tender ships, and is visited by aircraft carriers and other vessels. The number of both military and commercial vessels is expected to increase with the planned military expansion.

*Table 15.2. Number of fish, by family, caught for aquarium use. Source: DAWR.*

| FAMILY | NUMBER OF FISH |
|---|---|
| Pomacentridae | 1,440 |
| Acanthuridae | 418 |
| Chaetodontidae | 178 |
| Labridae | 140 |
| Apogonidae | 121 |
| Pomacanthidae | 97 |
| Lutjanidae | 85 |
| Siganidae | 53 |
| Zanclidae | 46 |
| Scaridae | 4 |

Ship groundings on Guam's reefs are inevitable due to the frequency of typhoons affecting the island. At this time, over 130 vessels are listed in NOAA's Abandoned Vessel Inventory database for Guam (http://response.restoration.noaa.gov/dac/vessels/vess_main.html. During a recent NOAA study, nine of the 31 vessels surveyed (29%) were located on coral reef, hardbottom or lagoonal fauna (Helton et al., 2003). Navigational buoys also pose a problem as storm swells can drag them onto the reef, causing damage to coral and other habitats. In addition, since 2004, three vessels have grounded due to navigator error. The October 2004 grounding of a foreign longliner at Western Shoals, a popular dive site, caused substantial damage to an area of high coral cover (Figure 15.12); the other two groundings caused minor damage. A vessel carrying illegal immigrants from Saipan caused an unknown amount of damage in May 2007 when it was abandoned at the Guam National Wildlife Refuge.

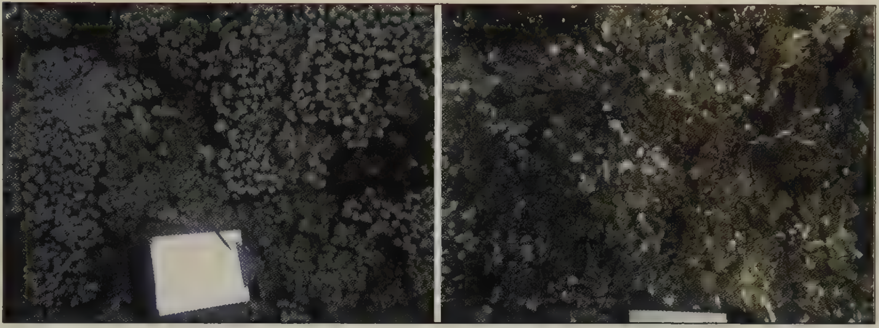


*Figure 15.12. Undamaged (left)and damaged (right) reef at the 2004 grounding site of a foreign longliner on Western Shoals, a popular dive site. Photo: V. Brown.*

## Marine Debris

While not a major threat, marine debris continues to impact Guam's reefs. According to the Guam Coastal Management Program (GCMP), over 2,500 bags of debris weighing nearly 12 metric tons were collected during the 2007 International Coastal Cleanup, while 1,800 bags weighing about 11.5 metric tons were collected in 2005 and about 900 bags weighing 5.6 metric tons were collected in 2004. As in previous years, beverage containers were the most common items collected in 2004 and 2006, with cigarette filters, plastic bags and cups, plates and food wrappers also collected in high numbers. Car batteries, appliances, tires, car parts and abandoned fishing gear were also collected during both events. The Coastal Cleanup data indicate that most of the marine debris found on the beaches and in the coastal waters of Guam is generated locally. The majority of this debris is from land-based activities, such as barbeques, festivals, sports and days at the beach (The Ocean Conservancy, 2007). Litter washed from streets, parking lots and storm drains also contributes to the debris found on Guam's shores.

Discarded fishing nets are occasionally found wrapped around coral colonies (Figure 15.11), with partial or full colony mortality apparently a result of abrasion and smothering. Nearly 200 fishing nets were collected during the 2006 International Coastal Cleanup. DAWR has also removed numerous abandoned fishing nets since 2004. There were three cases of marine debris recorded by towed-divers participating in the 2005 Marianas Archipelago Reef Assessment and Monitoring Program (MARAMP) expedition, including a single large trawl or seine net off of Cocos Island, a trawl net near Togcha Bay and an old automobile off of Asan Point.

## Aquatic Invasive Species

No additional work on aquatic invasive species has been conducted since the 2005. However, there is concern that the expected increase in military and commercial shipping activity in Apra Harbor as a result of the military expansion will increase the risk of impact to Guam's reefs by aquatic invasive species. Although diverse tropical systems appear to be more resistant to impacts from introduced species (Hutchings et al., 2002), such impacts, particularly from invasive algae species, have occurred elsewhere and have the potential to significantly alter native ecosystems (Russell, 1992).

## Security Training Activities

The Department of Defense continues to carry out training activities on Guam that have the potential to impact coastal waters and adjacent reefs. The frequency of these activities, including underwater demolition and landing craft exercises, appears to have lessened since 2004, but their cumulative impact remains a concern. The impacts of multiple training activities in the W-517 Warning Area, which encompasses Santa Rosa and Galvez Banks, are not known. An increase in the type and frequency of security training activities is expected in association with the overall military expansion. The Navy is currently preparing separate environmental impact statements to address current levels of training activity and potential impacts of enhanced training activity proposed for the Marianas Islands Range Complex and additional training required for the marine relocation.

## Offshore Oil and Gas Exploration

There are currently no oil or gas prospects identified near Guam.

## Other

### *Crown-of-thorns Sea Star (Acanthaster planci)*

Guam has been affected by widespread outbreaks of the crown-of-thorns sea star (COTS) since at least 2004. According to the definition used for surveys on the Great Barrier Reef, a local COTS population is considered in "active outbreak status" when densities reach or exceed 30 individuals/hectare (CRC Research Center, 2003). Manta tow surveys (English et al., 1997) conducted by the UOGML between February and October 2006 at numerous sites around Guam indicated widespread COTS outbreaks and large-scale coral mortality (C. Caballes, unpub. data). Large aggregations, ranging from approximately 100 to over 1,600 individuals per 20-minute tow, were observed at six of 17 survey sites (Figure 15.13). Preferred prey species, including *Montipora* spp. and *Acropora* spp., were almost wiped out at most sites, and COTS had begun feeding on less-preferred corals such as massive *Porites* spp. and *Goniopora* spp. Estimated COTS densities of 50-61 individuals per hectare were observed on tows at three of the 17 survey sites and between 14-26 individuals/hectare at three additional sites. Most striking, however, were observations of densities greater than 450 individuals/hectare in Pago Bay and nearly 1,500 individuals per hectare at Tanguisson Point.

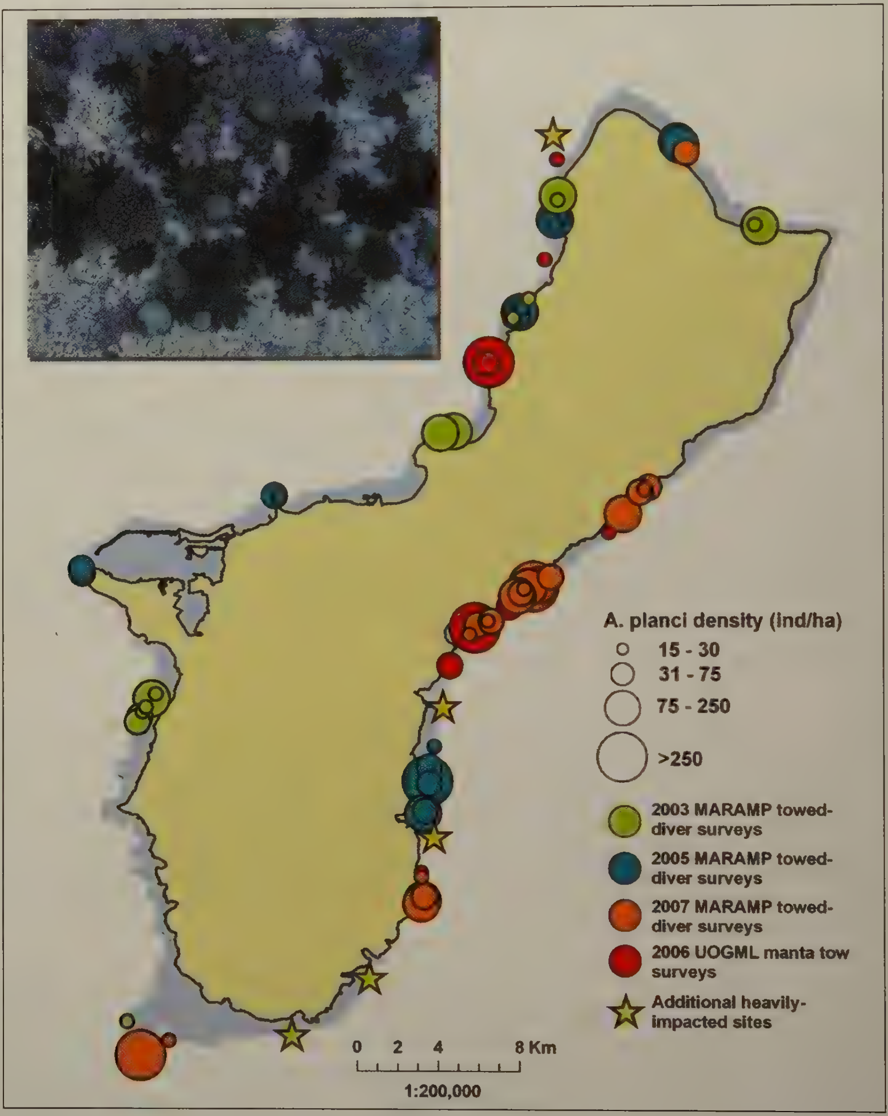

A. planci density (ind/ha)
15 - 30
31 - 75
75 - 250
>250
2003 MARAMP towed-diver surveys
2005 MARAMP towed-diver surveys
2007 MARAMP towed-diver surveys
2006 UOGML manta tow surveys
Additional heavily-impacted sites
0 2 4 8 Km
1:200,000

*Figure 15.13. Crown-of-thorns sea star densities around Guam recorded during manta tow surveys carried out by the UOGML in 2006 and MARAMP towed-diver surveys in 2003, 2005 and 2007. UOGML manta tow transect length was recorded, but width was not specified; a conservatively-estimated width of 40 m was used in density calculations. COTS density for MARAMP towed-diver surveys was calculated using the known 10 m transect width and an average tow segment length of 0.2 km. Sites where additional observations indicated high levels of COTS predation since 2005 are marked by yellow stars. The photo is of a high-density COTS aggregation near Tanguisson Point in April 2006. Photo: P. Schupp; map: D. Burdick.*

Towed-diver data from the 2003, 2005 and 2007 NOAA MARAMP expeditions provide further indication of COTS outbreaks at numerous locations around Guam over the last several years, with an increase in outbreak intensity observed with each subsequent research cruise (Figure 15.13).COTS aggregations and extensive COTS-related coral mortality have also been observed at several other sites not surveyed by the UOGML or during the MARAMP expedition (D. Burdick, pers. obs.). The widespread, persistent nature of these outbreaks, as well as observations of high COTS-predation mortality among less-preferred coral species, suggest that these outbreaks have had, and are continuing to have, a severe impact on many of Guam's reefs.

## CORAL REEF ECOSYSTEM—DATA-GATHERING ACTIVITIES AND RESOURCE CONDITION

Several monitoring, assessment, and research activities have been conducted on Guam since 2004. These activities measure several aspects of Guam's reef community that are important to coral reef management, including benthic habitat, water quality, biological communities associated with coral reefs (e.g., fishes and macroinvertebrates) and socio-economic information. A comprehensive list of all recent or ongoing studies related to Guam's coral reefs is provided in Table 15.3, and the locations of monitoring sites are shown in Figure 15.14. Two additional MARAMP research cruises were conducted since the September 2003 expedition, including one from October 3-9, 2005, and another from May 12-15, 2007 (NOAA PIFSC-CRED; http://www.nmfs.hawaii.edu/cred). The science teams for the Guam leg of MARAMP cruises have included staff from the NOAA Pacific Islands Fisheries Science Center (PIFSC) Coral Reef Ecosystem Division (PIFSC-CRED), the NOAA Pacific Islands Regional Office, Guam DAWR, the National Park Service (NPS) and the UOGML. Most of the ecological and oceanographic assessments conducted during the 2003 expedition were repeated at the same sites in later years. Santa Rosa Bank was not surveyed during the 2007 expedition due to time constraints. Most of the 2007 assessment results were not available for this report, but will be provided at a later date.

*Table 15.3. Summary information for Guam's coral reef monitoring, research and assessment activities. Source: D. Burdick and V. Brown.*

| ACTIVITY CATEGORY | AGENCY | YEARS | ACTIVITY DESCRIPTION | COLLECTION |
|---|---|---|---|---|
| **Marine Preserve Monitoring** | DAWR | 7 | Assessment of the effectiveness of Guam's marine preserves on Food Fish populations. Visual transects and interval counts are used to assess fish species. | Every 1-2 years |
| | UOGML | 1 | Investigation of the connectivity between marine preserves and exploited reefs using larval tracking methods | One time |
| | | 1 | Assessment of spillover of adult target fish species from Marine preserves into adjacent areas | One time |
| | | 1 | Assessment of abundance of target fish groups in marine preserves and adjacent control sites; part of larger investigation of relationship between herbivorous fish, algae and nutrient interactions within marine preserves | One time |
| | | 1 | Investigation of role of soft coral as fish habitat within a marine preserve | One time |
| **Sedimentation** | NPS | 4 | Assess the level of sedimentation and its affect on reefs in the WAPA. Data collected include total sediment, percent organic, percent carbonate, sediment size, water temperature, light penetration, benthic cover and coral recruitment. | Monthly |
| **Erosion** | NPS | 4 | Land based monitoring of erosion rates in burned versus non-burned areas. In addition, erosion flumes are being used to assess possible badland mitigation techniques. | Weekly |
| **Oceanography and Water Quality** | Guam EPA | >20 | GEPA 305b, Water Quality Report to Congress | Biennially |
| | | | Recreational Water Quality (microbial) | Weekly |
| | | | Monitoring wells, golf courses and restoration sites | Quarterly |
| | | 3 | Environmental Monitoring and Assessment Program | Biennially |
| | NOAA PIFSC-CRED | 5 | Monitoring of: 1) conductivity, temperature, depth, dissolved oxygen, and chlorophyll to a depth of 500 m using deepwater conductivity, temperature and depth (CTD) sensors; 2) temperature, salinity, and temperature at multiple sites using shallow-water CTDs; 3) chlorophyll and nutrients (nitrate, nitrite, silicate, phosphate) concurrent with the deep and shallow-water CTDs; 4) temperature at 0.5 m using two SST buoys; and 5) temperature at depths between 0.5 and 30 m using three subsurface temperature recorders | Biennially |
| | UOGML | 3 | Evaluation of the effectiveness of using soft corals as bioindicators of water quality | One time |
| | | 1 | Acquisition of monthly measurements of NOx, RP, Si, and salinity at 11 reef flat sites; part of larger investigation of relationship between herbivorous fish, algae and nutrient interactions within marine preserves | One time |
| | UOG WERI | 1 | Investigation of relationship between nutrients and *Enteromorpha clathrata* blooms in Tumon Bay (Denton et al., 2005) | One time |
| | | 1 | Determination of impacts of leachate from Ordot dump on marine communities in Pago Bay (Denton et al., 2006) | One time |
| | NPS/U.S. Geological Service | 1 | Development of detailed hydrodynamic model for the Asan Beach Unit of the WAPA. Data collected for five locations within Asan Bay include 1) current speed and direction throughout the water column 2) wave height, wave period, wave direction and tide level 3) near-bed water temperature, salinity, turbidity and PAR; and 4) near-surface water temperature, salinity and turbidity. The water level in Asan River as well as wind speed, wind direction, air temperature, rainfall and incident PAR will also be monitored. | One time |

*Table 15.3 (continued). Summary information for Guam's coral reef monitoring, research and assessment activities. Source: D. Burdick and V. Brown.*

| ACTIVITY CATEGORY | AGENCY | YEARS | ACTIVITY DESCRIPTION | COLLECTION |
|---|---|---|---|---|
| **Benthic Habitat** | NOAA PIFSC-CRED | 5 | Documentation of baseline conditions of the health of coral, algae and invertebrates, refine species inventory lists, monitor resources over time to quantify possible natural or anthropogenic impacts, document natural temporal and spatial variability in resource community, improve our understanding of the ecosystem linkages between and among species, trophic levels and surrounding environmental conditions. | Biennially |
|  | UOGML | 1 | Baseline assessment and long-term monitoring of benthic community at five permanent reef sites | Tri-monthly for 1st year; then biannually or annually |
| **Coral Disease** | UOGML | 1 | Baseline assessment of coral disease prevalence at 10 sites; benthic composition, coral species richness, bleaching, predation and other signs of compromised health were also assessed. | One-time |
|  |  | 1 | Monitoring of coral disease prevalence, coral community, signs of stress and disease and water temperature at four of the 10 baseline assessment sites. | Quarterly |
| **Fisheries Monitoring** | DAWR | >20 | Creel, participation, and boat-based surveys to obtain information including boating activity, fishermen participation, CPUE and species composition in order to monitor the health of the fisheries resources | Semi-weekly (on average) |
|  | NPS | 1 | Assessment of impacts of fishing within the WAPA | One time |
|  | UOGML | 1 | Characterization of previously identified reef fish spawning aggregations and sites in Piti Bomb Holes Marine Preserve and Asan Bay | One time |
| **Associated Biological Communities** | UOGML | 1 | Baseline assessment and long-term monitoring of fish and macroinvertebrate communities at five permanent reef sites | Tri-monthly for 1st year; then biannually or annually |
|  | NOAA PIFSC-CRED | 6 | Monitoring of reef fish communities using Rapid Ecological Assessments (belt transects, stationary point counts and roving diver surveys) and towed-diver surveys. | Biennially |
|  | UOGML / DAWR | 6 | Monitoring of specific Reef Check sites using community volunteers | Annually, when possible |
|  | UOGML | 1 | Assessment of COTS outbreaks using manta-tow surveys | One time |
| **Recreational Impacts** | GCMP | 1 | Assessment of impacts of motorized personal watercraft on water and sediment quality, benthic habitat and fish communities in East Agana Bay | One time |
| **Socioeconomic Information** | UOGML | 1 | Assessment of economic value of Guam's coral reefs and associated resources; the underlying motives and mechanisms behind the total economic value were also investigated by focusing on people's relationship with the marine ecosystems, local "willingness to pay" for coral reef conservation and the spatial variation of reef-associated economic values and threats. | One time |
|  |  | 1 | Determination of the non-extractive value of coral reef icon species | One time |
|  | UOG | 1 | Assessment of perceptions, values and level of awareness among Micronesian populations on Guam regarding coastal resources, particularly with regard to the marine preserves and differences in management systems (e.g., traditional marine tenure versus open access) | One time |
|  | GCMP | <1 | Evaluation of the effectiveness of GCMP's various public outreach activities and to identify the environmental issues of most concern to the public | Every 3-5 years |

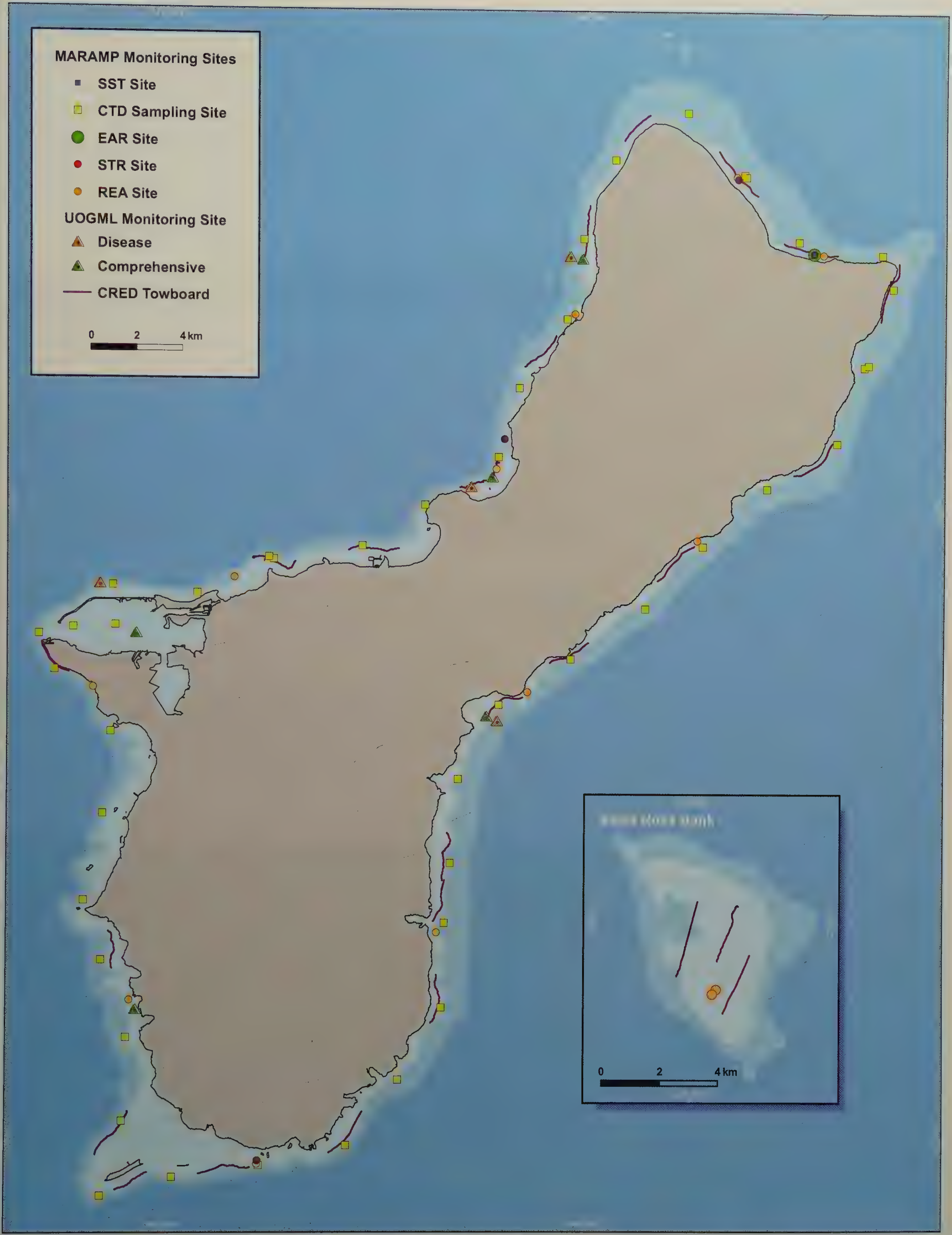

MARAMP Monitoring Sites
SST Site
CTD Sampling Site
EAR Site
STR Site
REA Site
UOGML Monitoring Site
Disease
Comprehensive
CRED Towboard
0
2
4 km
0
2
4 km

*Figure 15.14. The location of monitoring sites around Guam. Map: K. Buja.*

## WATER QUALITY AND OCEANOGRAPHIC CONDITIONS

Efforts to obtain water quality data relevant to coral reef management have increased in recent years, with biennial sampling of multiple parameters around the island occurring with Guam EPA's Environmental Monitoring and Assessment Program (EMAP). EMAP sampling was carried out in 2005 and 2006, but data analysis is not yet complete and the results will be presented at a later date. A summary of the results of Guam EPA sampling efforts prior to switching to the EMAP program is available in Porter et al. (2005). Included below are the latest results of two long-term water quality monitoring efforts, including Guam EPA's recreational beach water quality monitoring and water quality sampling activities conducted during the 2005 and 2007 NOAA MARAMP cruises. The results of an ongoing NPS study to determine the impact of sedimentation on the coral community within the Asan Unit of the WAPA are also discussed below.

### *Guam EPA Water Quality Sampling*

The Guam EPA continues to sample coastal recreational waters at more than 40 stations around the island every week, testing for *Enterococcus* bacteria, according to U.S. EPA requirements. A public advisory is issued when an instantaneous reading of bacteria exceeds 104 units per 100 ml of water. In fiscal year (FY) 2005, 27% of 2,055 samples exceeded these levels, resulting in 556 advisories (Table 15.4); there were 604 advisories from 2,196 samples (28%) in FY 2006. Using *Enterococcus* as a bacterial indicator of sewage pollution, water quality has not improved since 2003, when 27% of samples exceeded standards and 551 advisories were issued. However, as mentioned in Porter et al.(2005), the use of *Enterococcus* as a bacterial indicator of sewage pollution may not be appropriate for tropical islands such as Guam, since it naturally occurs in the island's soil (independent of sewage pollution). Collins (1995) suggests that *Enterococcus* levels will predictably increase in Guam's coastal waters after rain events, as the bacteria are washed out of the soil.

*Table 15.4. Summary of recreational water quality monitoring sampling from 2005 to the third quarter of 2007. Source: Guam EPA.*

| NUMBER OF ADVISORIES PER QUARTER | | | | | TOTAL NO. OF ADVISORIES |
|---|---|---|---|---|---|
| **Region** | **1st** | **2nd** | **3rd** | **4th** | |
| 2005 Northern Subtotal | 66 | 34 | 12 | 88 | 200 |
| 2005 Southern Subtotal | 114 | 65 | 75 | 112 | 366 |
| **2005 Total** | **180** | **99** | **87** | **200** | **566** |
| 2006 Northern Subtotal | 50 | 36 | 29 | 133 | 248 |
| 2006 Southern Subtotal | 99 | 50 | 55 | 152 | 356 |
| **2006 Total** | **149** | **86** | **84** | **285** | **604** |
| 2007 Northern Subtotal | 76 | 30 | 21 | - | 127 |
| 2007 Southern Subtotal | 182 | 77 | 69 | - | 328 |
| **2007 Total** | **258** | **107** | **90** | **-** | **455** |

### *MARAMP Oceanographic/Water Quality Data*

Measurements of chlorophyll and nutrient concentrations, conductivity temperature and depth, were obtained during the 2003, 2005 and 2007 MARAMP expeditions at numerous sites around the island. A list of MARAMP water quality and oceanographic data collecting activities is provided in Table 15.3; methods are described in detail at http://www.nmfs.hawaii.edu/cred. The locations of monitoring around Guam are provided in Figure 15.14. Analysis of *in situ* water samples collected around Guam revealed relatively low spatial variability in measured nutrients during the sampling period. The highest nutrient concentrations were in the Apra Harbor region and increased with depth. There also appeared to be slightly elevated nutrient concentrations in the surface waters north of the Pago Bay region and increased levels in total nitrogen (nitrate plus nitrite) concentrations at all depths in the TBMP.

### *National Park Service Sedimentation and Coral Recruitment Studies*

Since October 2003, WAPA, a unit of the NPS, has been monitoring sediment collection rates on park coral reefs in Asan Bay (Minton, 2005, Minton et al., 2005). The goal of this work has been to increase understanding of the spatial and temporal dynamics of sediments onto the park's coastal reefs, in order to better assist the park staff with their coral reef management efforts.

*Methods*

Spatially intensive surveys, covering 25 sites spaced across the roughly 3.5 km-long Asan Bay, were conducted for one year (October 2003-November 2004), and continuous long-term monitoring (November 2004-present) has continued at selected sites (Figure 15.15). At each sampling site, two sediment samplers, each comprised

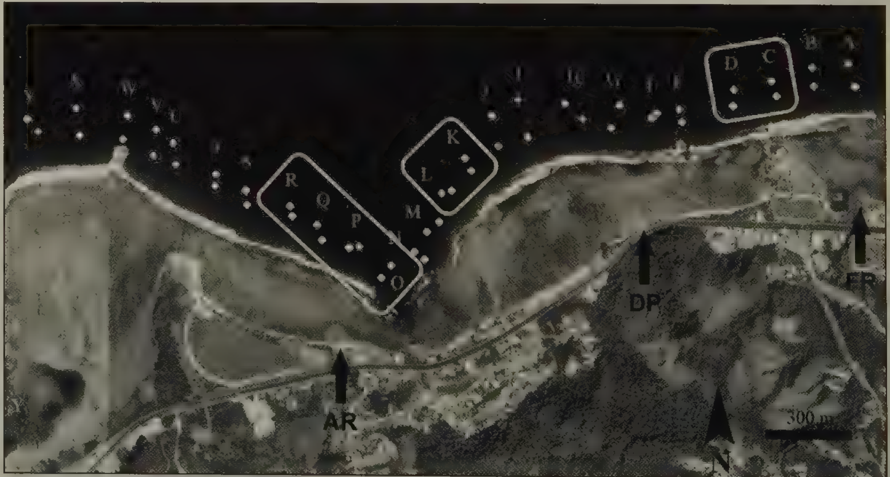


*Figure 15.15. Sediment and coral recruitment study sites in Asan Bay, Guam. Coral recruitment study sites (circled) were a subset of locations where NPS conducted three years of sediment monitoring. Each lettered sediment site was comprised of two sediment collectors, one placed at 10 m and a second at 20 m. Coral recruitment arrays were placed only at the deepwater locations. AR=Asan River outlet through Asan Cut; DP=Runoff drainage pipe; FR=Fonte River outlet. Source: Minton and Lundgren, 2006.*

of three PVC tubes, were deployed, one each at 10 and 20 meters depth. After three weeks, the collectors were retrieved and sediments were processed in the laboratory to measure total dry weight, percent organic material and percent $CaCO_3$. A grain size analysis was also conducted to determine the proportion of coarse, fines and silts in the sediment samples. Coral recruitment to settling plates at eight of the sediment study sites was also examined during this period to see if a link existed between coral recruitment and coastal sediments (Lundgren and Minton, 2005; Minton and Lundgren, 2006; Minton et al., in prep). Coral recruitment arrays, comprised of both PVC and terra cotta settlement plates, were deployed at eight sites at 20 m depth that represented a range of sedimentation levels (Figure 15.16).

*Results and Discussion*

Both spatial and temporal patterns were apparent in the sediment collection rates in Asan Bay. Sediment collection rates were best explained by proximity to a sediment point source, such as a river mouth or a drainage pipe (Figure 15.16). Additionally, heavy rainfall events were found to be more important than total rainfall. The seasonal nature of rain events on Guam resulted in significantly higher sediment collection rates during the wet season (July-December). A significant sediment flushing event was observed at the start of the wet season, following the first large storm event of the summer. This large rain event presumably moved sediments that had collected in the watershed or streams during the low intensity rain events common during Guam's dry season (January-June) into the coastal waters. Flushing events may be particularly harmful to Guam's coastal reefs because they occur coincident with the annual coral mass spawning. Coral gametes and larvae have been shown to experience high mortality when exposed to Guam's sediment-laden water (Richmond, 1993).

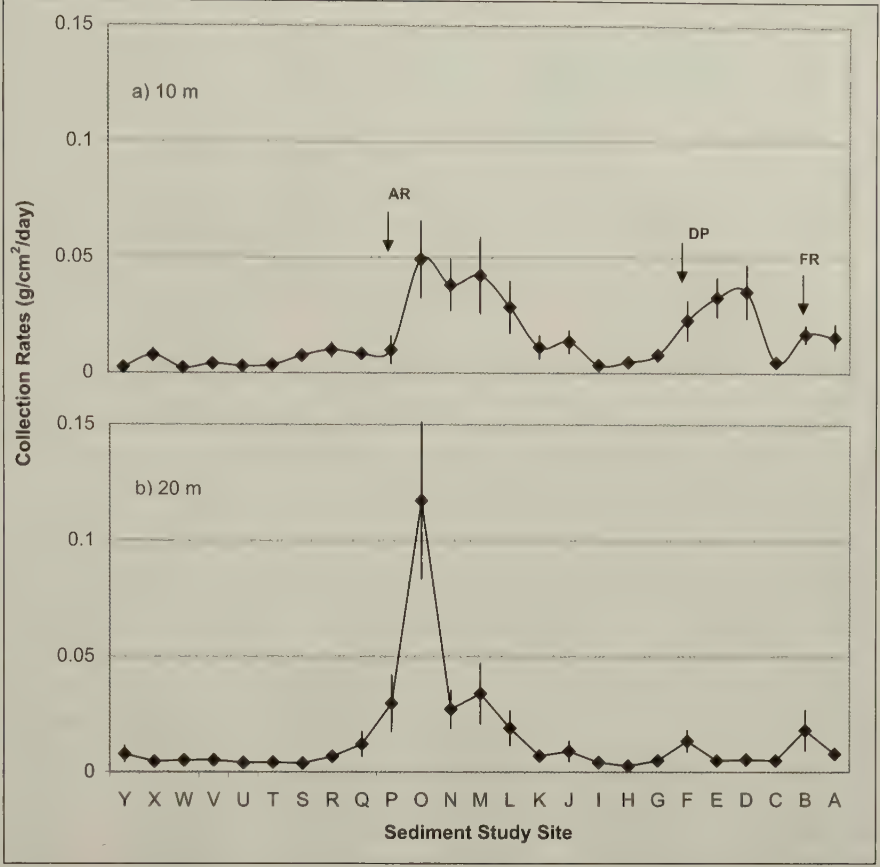


*Figure 15.16. Mean (± 1 SE) sediment collection rates (g/cm²/day) at, a) 10 m and b) 20 m deep sediment study sites in Asan Bay. Site reference letters correspond with site locations in Figure 15.15. Arrows represent the approximate location of three sediment point sources listed above. Data are for September 2003-November 2004. Source: Minton, 2005.*

Over the course of the two year study, recruitment rates across Asan Bay were found to be low, with an average of approximately three coral recruits/m². Recruitment rates were independent of sediment collection rates, and did not appear to be a result of post-settlement mortality. Instead, low recruitment may have been the result of pre-settlement factors, including poor larval supply to the bay, poor water quality conditions within the bay and/or poor benthic conditions that interfered with successful larval settlement. This study highlights a trend of declining coral recruitment on Guam's leeward reefs. In studies conducted prior to 1981 (Neudecker, 1976; Birkeland et al., 1981; Neudecker, 1981), a two-order of magnitude higher recruitment rate was observed compared to 1989 studies using nearly identical methodologies (Birkeland and Sakai in Birkeland, 1997; Chirichetti in Birkeland, 1997). The results for Asan Bay are consistent with these later studies, further suggesting that this trend is not the result of annual variation but a real decline in successful coral recruitment on Guam's reefs.

## BENTHIC HABITATS

Significant progress has been made in assessment, monitoring and mapping of benthic habitats on Guam since 2004. The first island-wide coral disease assessment was conducted in 2006 and 2007, with long-term disease monitoring continuing for established sites. Coral and algae-focused Rapid Ecological Assessments (REAs), as well as extensive towed-diver benthic surveys were conducted during 2005 and 2007 MARAMP cruises, but with the exception of the algae REA surveys conducted in 2007, only the results of the 2005 surveys were available for inclusion in this report. The mapping of nearshore (0-30 m) benthic habitats was conducted by the UOGML in 2006, building upon the 2003 mapping efforts of the NOAA Center for Coastal Monitoring and Assessment, Biogeography Branch (CCMA-BB), while multibeam bathymetry and backscatter data were collected for deeper waters (>20 m) around the island during the 2007 MARAMP cruise.

### *Coral Disease Prevalence and Long-Term Monitoring (UOGML)*

The coral disease monitoring program continued from the initial baseline surveys in 2006 that established disease prevalence on Guam reefs. A total of 10 reefs around Guam have been surveyed for benthic composition, coral species richness, coral disease prevalence, bleaching, predation and other signs of compromised health. Of these 10 sites, four sites, including Luminao and Tumon Bay (shallow reef flat communities) and Pago Bay and Double Reef (deeper reef slope/shelf communities), were selected for long-term monitoring of the coral community, signs of stress and disease and water temperature (Figure 15.14).

*Methods*

Sites were surveyed using a minimum of three 20 x 2 m belt transects laid perpendicular to shore at depths ranging from 2 m-7 m. At sites with several distinct coral communities, such as Tumon Bay and Double Reef, additional transects were laid within each distinct reef zone. The Line Intercept method (English et al., 1997) was used to characterize benthic composition along each transect; all hard coral colonies were counted within each belt. Colonies were examined individually for signs of disease, predation, bleaching, algal overgrowth, silt damage and lesions of unknown cause. Photographs were taken of representative diseases, and corals were sampled when an underwater diagnosis could not be made or needed to be verified microscopically. All colonies exhibiting disease or compromised health were counted and identified to species. Permanent transect markers were established at the sites mentioned above in August 2006, and temperature data loggers were deployed at each site. Monitoring of the parameters mentioned above has taken place quarterly along these transects since then, and is expected to continue indefinitely.

*Results and Discussion*

The prevalence of diseases within each coral family was examined in order to determine how coral diseases were distributed taxonomically. Guam showed a strong link between disease prevalence and abundance per family (regression of generic abundance on total disease prevalence: $R^2=0.89$; $p<0.0001$). *Porites*, the most abundant coral genus on Guam reefs, was also the most impacted by a number of diseases; five out of the six diseases described previously affect various species within the genus. Because this genus represents the primary reef builder in Guam reefs, coral diseases that result in partial or full colony mortality have the potential to significantly affect community structure.

Monitoring along permanent transects has also revealed changes over time, but at present, only the Luminao data set has been analyzed. Transects at both Double Reef and Tumon Bay required re-positioning after transect markers were lost. Although less than one year of monitoring data have been collected to date, preliminary results suggest that long-term monitoring is likely to be very useful. Temperature loggers have been in place at Luminao continually since August 2006 and reveal a seasonal decline in water temperature beginning in September. March temperatures appeared to level off, and water temperatures are predicted to begin warming. Total disease prevalence increased greatly between August and November 2006, though values between transects were highly variable (Figure 15.17); this was attributed to an increase in observations of a white syndrome, which was affecting both branching and massive *Porites*. In general, disease prevalence at Luminao appears to be increasing over time; the initial assessment showed a mean prevalence of 6%, increasing to 30% by the following year. The data also suggest some correlation between temperature and disease; the highest prevalence values correspond to the period of warmest temperatures. This monitoring, combined with examining between-site differences, should allow an analysis of long-term trends, links with water temperature seasonality and changes in the coral community at each site.

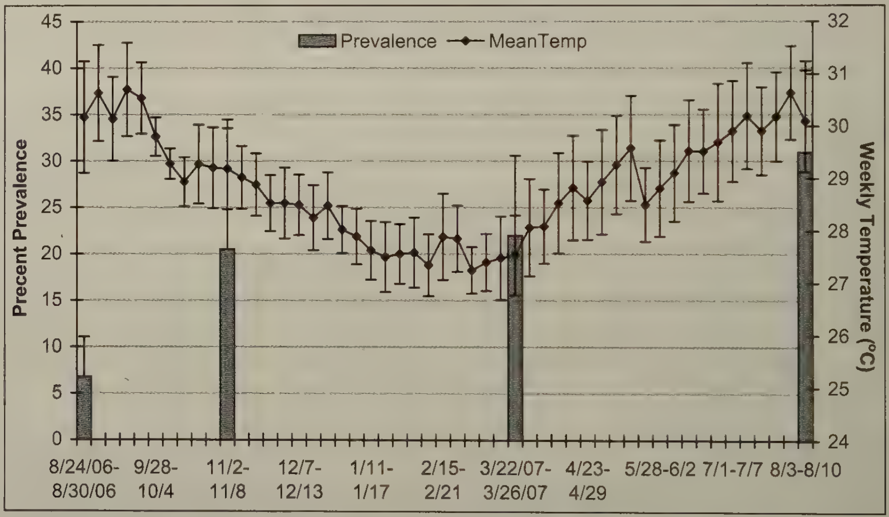


Figure 15.17. Mean total disease prevalence and mean weekly temperature, Luminao Reef (Mean ± SD; n=3 transects). Source: L. Raymundo, unpub. data.

## UOGML Long-Term Monitoring: Benthic Community

In 2006, the UOGML established permanent transects at five long-term monitoring sites around Guam. Although Guam's coral reefs have been studied since the early 1970s, no permanent sites were ever established with the explicit objective of studying long-term change in coral communities. While temporary transects were used for a number of studies, a lack of permanent transects and long-term baseline data have made it difficult to examine the effects of multiple natural and anthropogenic impacts. In addition, few studies have assessed the reef community in its entirety or examined interactions between components. It is anticipated that the sampling design outlined below will result in the collection of robust baseline data in order to assess the potential impacts of future natural and anthropogenic disturbances on Guam's reefs and to quantify their recovery. The monitoring of these sites will continue indefinitely, resulting in a reef monitoring database. The methods and results of baseline benthic habitat surveys conducted in 2006 are presented below.

*Methods*

In consultation with DAWR, five sites were selected for monitoring, including Pago Bay, Fouha Bay, Western Shoals, Tumon Bay and Double Reef (Figure 15.14). Four permanent 50 m transects were established at each site within a depth range of 3-10 m. Each site will be surveyed every three months until mid-2008, after which monitoring will be conducted on a biennial or annual basis.

The benthos associated with each transect was filmed using an under-water video camera. The video footage was analyzed using CORALID software (M. Claereboudt, unpub. data). For each transect, total percent cover was determined for every benthic category. For the purposes of this report, these were subsequently pooled into six general categories: Hard Coral (scleractinian corals), Macroalgae, Turf Algae, Crustose Coralline Algae (CCA), Abiotic (all non-living categories, such as reef substrate) and Other (sponges, soft corals, anemones). The data presented below were collected from the first sampling period of the monitoring program; only two of the four transects were surveyed at each site during this time. The full survey regime will be carried out during subsequent sampling periods.

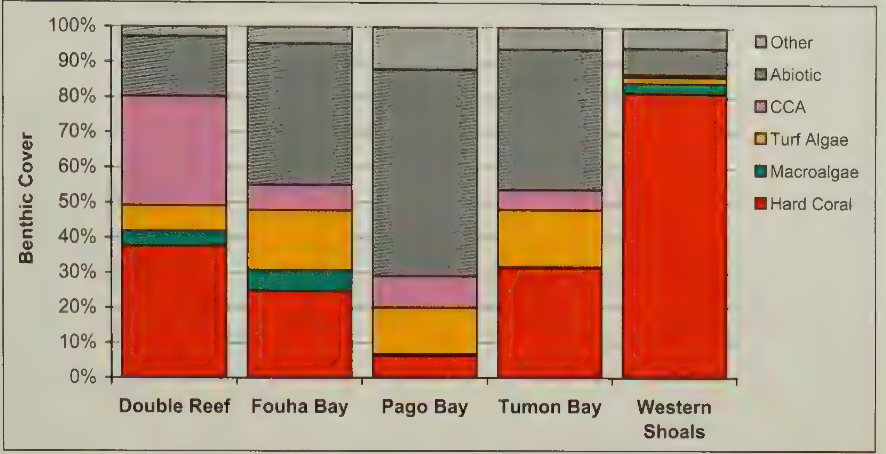


*Figure 15.18. Percent benthic cover using generalized categories: Hard Coral, Macroalgae, Turf Algae, Crustose Coralline Algae (CCA), Abiotic (all non-living categories, such as reef substrate) and Other (such as sponges, soft coral, anemones). Source: P. Schupp, unpub. data.*

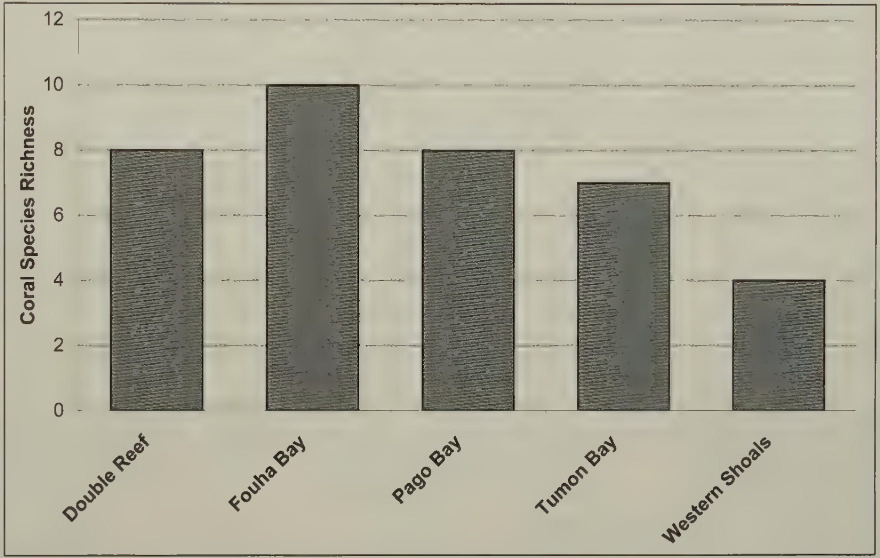


*Figure 15.19. Coral species richness for each monitoring site. Source: P. Schupp, unpub. data.*

*Results and Discussion*

Percent cover data is consistent with field observations of other benthic organisms collected at the same time. For example, Pago Bay has a high percentage of dead coral, which is in accordance with an increase in the size of the COTS population over the past few years. It is possible that much of the observed coral mortality has been the result of COTS predation. Fouha Bay, which receives a large input of land-based sediment (and possible nutrient influx), exhibited the second lowest coral cover. Western Shoals, on the other hand, had the highest hard coral cover (about 85%) but the least number of coral species (Figures 15.18 and 15.19). Like the rest of Apra Harbor, Western Shoals is dominated by large stands of *Porites rus*. Coral cover and species richness in Tumon Bay were similar to that of Double Reef. While the Tumon Bay site does not appear to be impacted by sedimentation, it has, like Pago Bay, experienced high numbers of COTS in recent years.

## *MARAMP Coral and Algae REA and Benthic Towed-Diver Surveys*

### Coral Community REA

*Methods*

REA surveys of coral communities were conducted at several sites around Guam and two sites at Santa Rosa Bank (Figure 15.14) in October 2005 by NOAA PIFSC-CRED using methods that have been applied at numerous other Pacific reef locations by PIFSC-CRED since 2002 (detailed methodology can be found at http://www.nmfs.hawaii.edu/cred). Several parameters were calculated from recorded data that collectively describe community structure, including coral percent cover, biodiversity, relative abundance, colony density and size-frequency distribution.

*Results and Discussion*

Twenty-six genera of scleractinian corals, as well as several taxa of octocorals including *Heliopora coerulea*, were recorded within belt transects. *Porites* dominated the coral fauna at Guam, while *Favia*, *Montastrea*, *Pocillopora* and *Porites* dominated the two sites surveyed at Santa Rosa Bank. Coral cover ranged from 11.8% on the southwest side of Guam to 38.2% on the west side of Guam (Figure 15.20). Average coral cover at Guam was 26.1% ± 3.6% standard error (SE). Average coral cover at Santa Rosa Bank was 19.1% ± 6.4% SE. Size frequency distributions from Guam and Santa Rosa

Bank are highly similar. Colonies measuring <20 cm maximum diameter characterized the coral community structure at both Guam (83.4% of colonies) and Santa Rosa Bank (87.9% of colonies).

## Algal Community REA

### *Methods*

Quantitative algae community surveys were conducted at nine of the 11 established REA sites around Guam in 2005 and 10 of the sites in 2007 (Figure 15.14) using an REA protocol developed specifically for remote island ecosystems (Preskitt et al., 2004). The two REA sites established at Santa Rosa Bank were not surveyed in 2007. Photographs of 12 quadrats sampled at each site were taken for percent cover analysis. Additionally, relative abundance of macroalgal genera or functional groups and voucher specimens were collected from each photoquadrat.

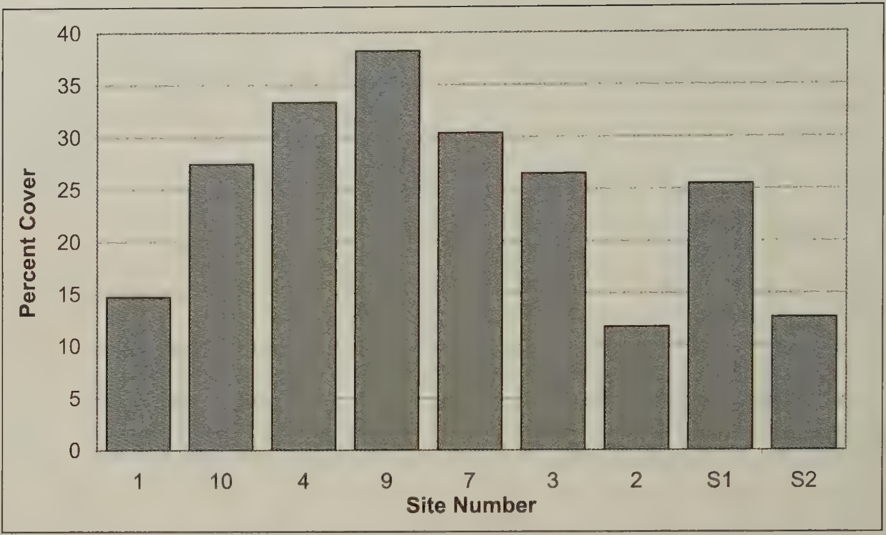


*Figure 15.20. Percent live coral cover for each REA site determined with the line-intercept method (102 points/site). Source: PIFSC-CRED, unpub. data.*

### *Results and Discussion*

Guam has a relatively diverse algal flora, with more genera than other islands in the Mariana Archipelago. A total of 16 green algae genera, 21 red algae genera and four brown algae genera were recorded inside sampled photoquadrats around Guam and Santa Rosa Bank during the 2005 MARAMP expedition. *Padina* sp., rarely seen at the other islands, was locally abundant, especially on the southwest side of the island. Santa Rosa Bank was dominated by macroalgae, particularly from the genera *Caulerpa*, *Avrainvillea*, *Dictyosphaeria*, *Halimeda*, *Microdictyon* and *Udotea*. Turf algae and cyanobacteria were also common, while very little crustose coralline algae was observed. A total of 11 green algae genera (22 species), 16 red algae genera (19 species) and four brown algae genera (five species) were recorded during the 2007 expedition. Some algal communities exhibited monotypic dominance, while others were very diverse. The most conspicuous macroalgae at many of the sites were *Halimeda* spp. and *Padina* spp. Turf algae and cyanobacteria dominated most sites, and crustose coralline algae were also present. Relative abundance of macroalgae at several sites around Guam differed between 2003 and 2005 sampling periods (Tribollet and Vroom, 2007), although the causal factors are not clear.

## Benthic Towed-Diver Survey

### *Methods*

A total of 23 benthic towed-diver surveys were completed around Guam in 2005 (Figure 15.14). Hard coral cover averaged 23% island-wide (range 0-75%), corresponding well with average coral cover estimated from the REA surveys (26.1% ± 3.6% SE). When divided into general regions (west/southwest, west/northwest, east/northeast, east/southeast), average coral cover was similar in the W/NW, E/NE and E/SE regions (25%, 26%, and 26%, respectively; Figure 15.21A). Coral cover was lowest in the W/SW region (12%).

### *Results and Discussions*

Additional coral observations included:

- West/southwest: The highest coral cover (average 49%, range 30.1-62.5%) was at southern reefs of Cocos Island;
- West/northwest: The highest coral cover (average 49%, range 30.1-62.5%) was found during a towed-diver survey between Hila'an Point and a location 1.1 km to the southwest of Haputo Point. Divers noted massive *Porites* spp. dominated the reef, which was also marked by low levels of COTS predation (54 recorded during the 50-minute survey);
- East/northeast: The highest coral cover (average 37%, range 30.1-62.5%) was noted in an area 2.7-5.2 km west of Pati Point;
- East/southeast: The highest coral cover (average 39%, range 10.1-62.5%) was noted on a survey near Togcha Bay.

Stressed coral was recorded at an average of 4% for all of Guam (range 0-40%). The majority of surveys recorded average stress levels of between 0-4%; however, certain areas, particularly in the east/southeast, exhibited significantly higher stress levels. Additional observations of stressed corals included:

- The survey in the vicinity of Togcha Bay recorded high levels of coral stress (average 19%, range 1.1-40%). Divers noted the presence of increased sedimentation, diseased coral and dead encrusting coral;
- A subsequent survey further south (ending at Talofofo Bay) recorded an average of 5% stressed coral (range 0-30%). Divers noted COTS predation, abnormal/diseased massive *Porites* spp. and *Diploastrea heliopora* colonies that showed signs of disease (yellow blotches);
- The towed-diver survey completed between Asiga Point and Jalaihai Point recorded the highest levels of coral stress in Guam (average 24%, range 10.1-50%);

- The towed-diver survey completed between Agfayan Point and Aga Point also recorded high levels of coral stress (average 12%, range 1.1-40%). Divers noted *Pocillopora* spp. that showed signs of disease, along with live coral that appeared to be overgrown with algae;
- The towed-diver survey completed near Asgadao Island, towards the eastern tip of Babe Island, also recorded an average of 12% coral stress (range 1.1-40%);
- In the northeast, a towed-diver survey off of Jinapsan Beach recorded an average of 8% coral stress (range 0-30%). Divers noted *Pocillopora*, *Astreopora* and other species appeared white, apparently from COTS predation.

Macroalgae cover for Guam averaged 51% (range 0-100%; Figure 15.21B), while coralline algae averaged 7% (range 0-100%; Figure15.21C). The highest algal cover was noted during the towed-diver survey completed between Agfayan Point and Aga Point (average 86%, range 75-100%). Soft coral cover was low around Guam, with an average of 1% recorded island-wide (range 0-20%; Figure 15.21D). The highest level of soft coral cover (6%) was noted during the survey in the northwest region, north of Achae Point.

### Santa Rosa Bank

Three towed-diver surveys over 7.1 km were completed at Santa Rosa Bank in 2005 (Figure 15.14). The following observations were recorded:

- Hard coral cover averaged 8% (range 1.1-30%); this was similar to coral cover recorded in 2003 (average 8%, range 2-18%);
- Stressed hard coral remained low, averaging 0.27% (range 0 -1%);
- Soft coral cover was also low, averaging 0.23% (range 0-1%);
- Macroalgae dominated the reef community (average 71%, range 1.1-100%), and was higher than macroalgae cover recorded in 2003 (average 43%, range 3-75%);
- Coralline algae cover was low (average 0.55%, range 0-5%), and was lower than coralline cover recorded in 2003 (average 7%, range 0-15%).

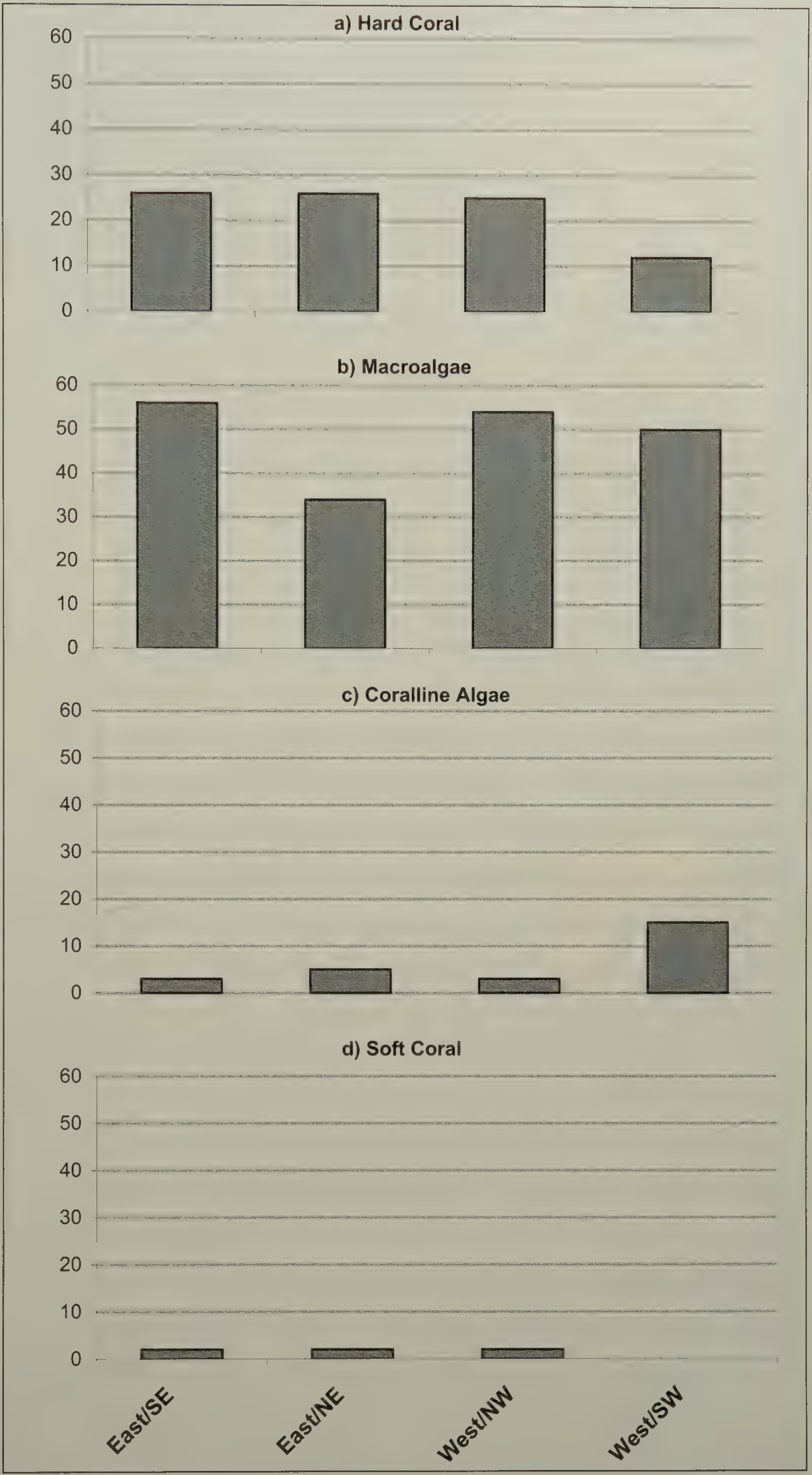


*Figure 15.21. Benthic cover by region from 2005 MARAMP towed-diver surveys. Total benthic cover measured by benthic towed-diver surveys consisted of a biotic component (coral, algae), along with an abiotic component (sand, rubble). Turf algal cover, carbonate pavement and rock were not recorded. Source: NOAA PIFSC-CRED, unpub. data.*

## Benthic Habitat and Bathymetric Mapping

### NOAA's Mapping Activities

NOAA's CCMA-BB produced a shallow water benthic habitat atlas in 2005 based on visual analysis of IKONOS satellite imagery (NOAA, 2005; Figure 15.22); the maps, derived products, and associated digital data are available from: http://ccma.nos.noaa.gov/ecosystems/coralreef/us_pac_mapping.html. PIFSC-CRED conducted limited multibeam and optical validation mapping around Guam during the MARAMP cruise in 2003. Additional multibeam data collection was carried out in 2007 by PIFSC-CRED. When combined with shallow-water LIDAR data, the bathymetric information provides

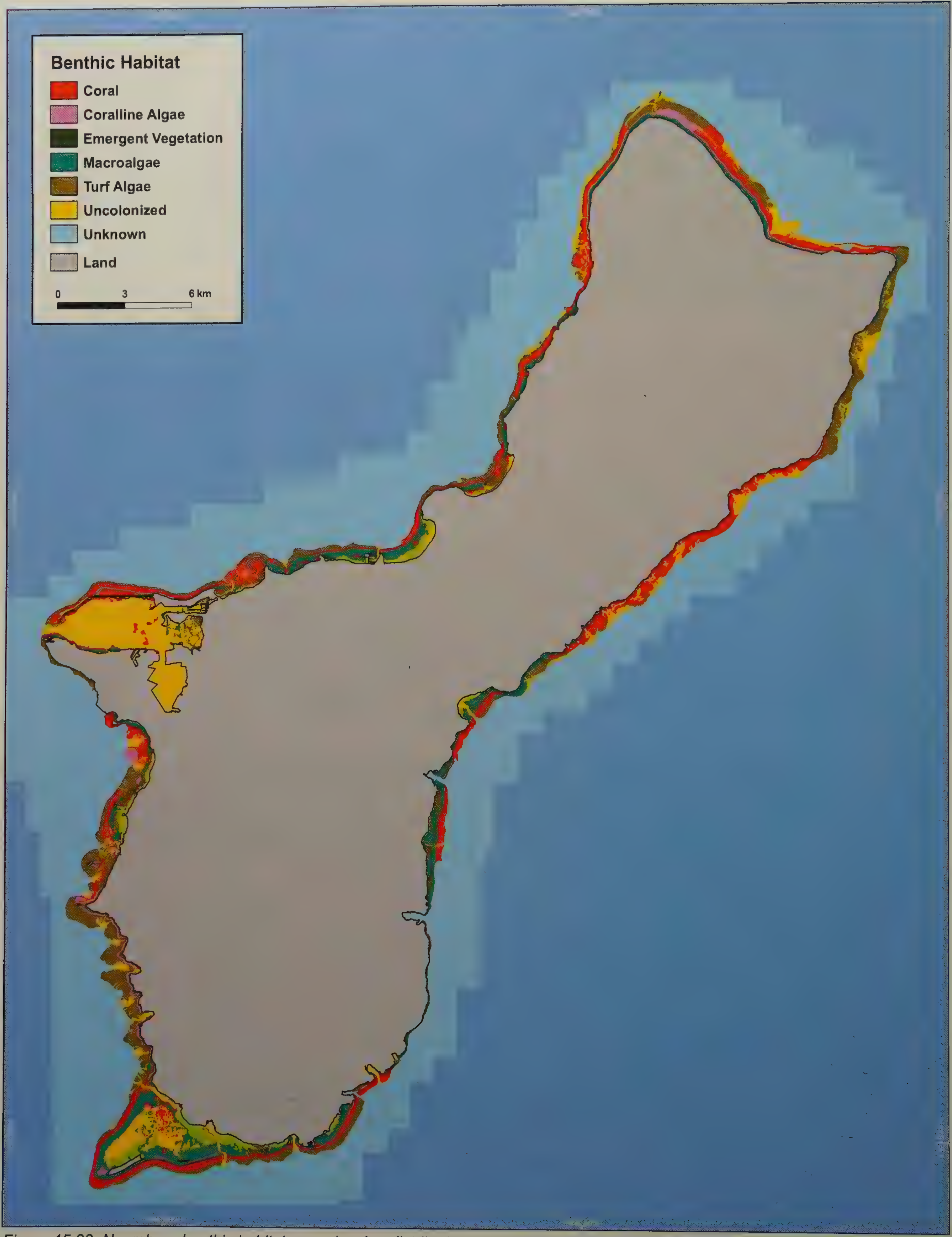

Benthic Habitat
Coral
Coralline Algae
Emergent Vegetation
Macroalgae
Turf Algae
Uncolonized
Unknown
Land
0
3
6 km

*Figure 15.22. Nearshore benthic habitat map showing distribution and extend of primary habitat types in Guam. Produced by CCMA-BB based on the visual analysis of IKONOS satellite imagery. Map: K. Buja.*

a nearly complete picture of Guam's nearshore marine bathymetry (Figure 15.23). The data are available for download from http://www.soest.hawaii.edu/pibhmc/pibhmc_cnmi.htm. The 2007 multibeam data should be available at the same Web site in 2008.

Guam Coastal Atlas
The UOGML, with support from the NOAA Pacific Islands Technical Assistantship program, developed an updated nearshore benthic habitat data set for Guam in 2006 based on the benthic habitat atlas developed by the NOAA's CCMA-BB in 2005. The updated data set was developed using the most recent, pan-sharpened IKONOS image mosaic available. By using a significantly smaller minimum mapping unit (0.05 ha or 0.125 acre) and additional groundtruthing data, this effort provided a higher level of detail for benthic habitats at selected areas of the coastline, including four of the five marine preserves and three focus areas. The updated benthic habitat data set was incorporated into the Guam Coastal Atlas

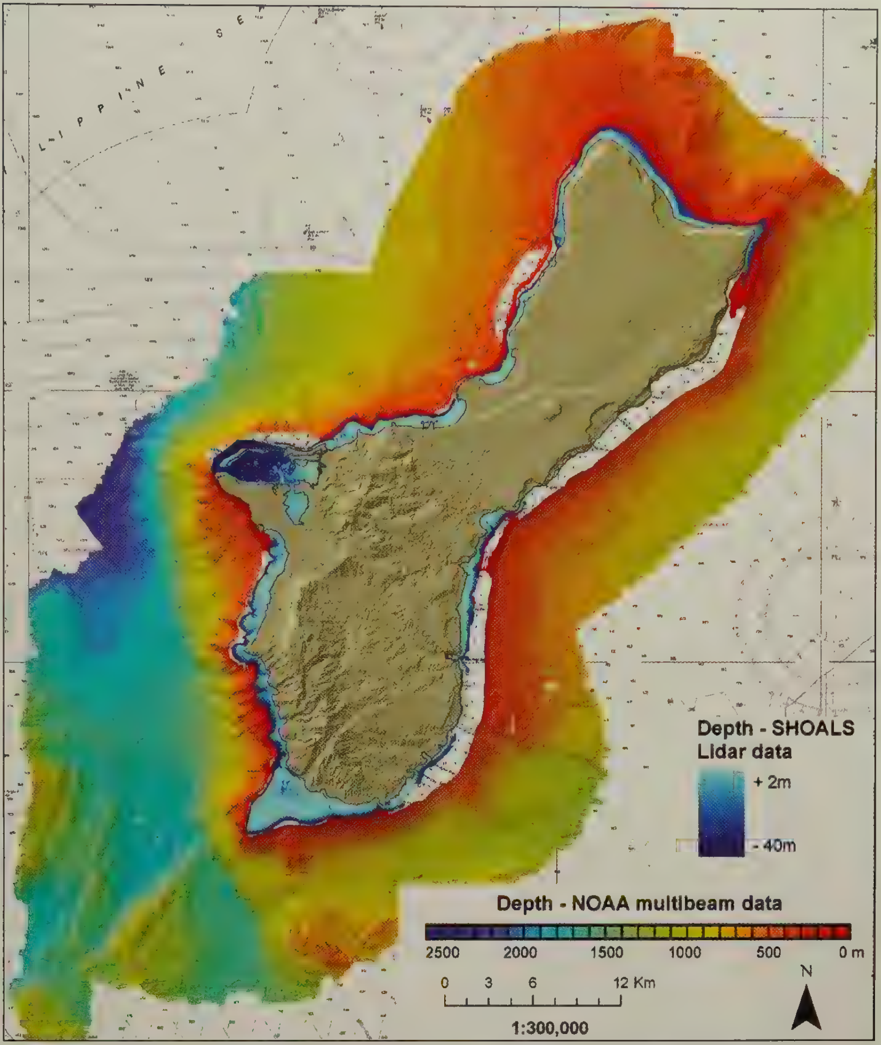


*Figure 15.23. Multibeam bathymetry data collected around Guam during the 2007 MARAMP cruise and SHOALS LIDAR data collected in 2001. The multibeam bathymetry data cover much of the deeper waters around Guam, while the SHOALS LIDAR data cover much of the shallow waters (0-30 m) around the island. Source: NOAA PIFSC-CRED.*

## ASSOCIATED BIOLOGICAL COMMUNITIES

Several studies have examined the biological communities associated with coral reefs since the 2005 report. As before, most of these studies were focused on reef fish communities. Additional data collected by DAWR as part of their creel survey program is provided in this section. Also provided are the results of REAs for fish and towed-diver surveys for fish and macroinvertebrates conducted during the 2005 MARAMP cruise, as well as macroinvertebrate data collected with towed-diver surveys during the 2007 cruises. Two stand alone studies of fish communities were also conducted since 2004, including an examination of the impacts of artisanal fishing on the reef fish communities within the WAPA, and preliminary findings from an investigation into the role of Marine Preserves in controlling herbivory levels and the effect on algae communities. Descriptions of these studies and their findings are presented below.

### *Guam Division of Aquatic and Wildlife Resources Creel Surveys*

The Guam DAWR, Fisheries Section has collected one of the largest, most continuous data sets on marine fisheries in the Pacific. The DAWR started collecting creel data in the early 1970s and has continued to refine its survey techniques and expand its scope over the years. The creel surveys are broken into two distinct categories: boat-based (or offshore) fisheries and shore-based (or inshore) fisheries. Boat-based fisheries primarily rely on small boats (3.6-14.6 m) for trolling and bottom fishing trips lasting up to two days. The majority of the boat based fishery catch consists of pelagic fish; however, reef fish are also an important component. Shore-based fisheries consist of fishing methods used from shore without a boat, and include methods such as nearshore casting, netting and spear fishing. The data collected by these surveys are entered into a database, quality controlled by DAWR staff and then expanded through a Visual FoxPro database application developed by the Western Pacific Fisheries Information Network, (WPacFIN) and DAWR to get the total estimated effort and harvest for the island. Table 15.5 provides a summary of reef fish harvest and CPUE by method for 2006. For more information about this program: http://www.pifsc.noaa.gov/wpacfin/guam/dawr/Pages/.

### *Shore-based Fisheries*

*Methods*

Each month, DAWR Fisheries staff randomly select four days for shore-based catch surveys. These survey days are divided into a day survey (0630-1200 hours) and a night survey (1900-2400 hours). For each survey day, one of three survey areas is selected for the day's efforts. DAWR staff then conducts fishermen-intercept interviews to determine the amount of effort, fishing method, species composition and the amount caught. Surveyors also note location, reef zone, and weather and tide conditions. These catch surveys are complemented by participation surveys that are conducted four times a month on randomly selected days. During participation surveys, the surveyor records all in-progress shore-based fishing participation. This includes time of day, locations, number of people, number of gear units, fishing method, reef zone fished, and weather and surf conditions. The surveyor drives through all three survey areas beginning at a randomly selected region. The direction of the survey, clockwise versus counter-clockwise, is alternated each survey day. Participation surveys are conducted during the day and at night. The participation survey is supplemented by an island-wide aerial survey. Aerial surveys are conducted twice a month, simultaneous with one weekday and one weekend participation survey. The aerial survey collects the same information as the participation survey, but surveys the entire coastline. The participation survey assesses total fishing effort, which is then expanded based on the creel data through the WPacFIN database to get the total estimated effort and harvest for shore-based fisheries.

*Table 15.5. Estimated reef fish harvest and CPUE for shore and boat based methods in 2006. Shore based data exclude seasonal runs of juvenile siganids and bigeye scads. *CPUE was calculated based on total catch including pelagic and deepwater species. **SCUBA spear measures are based on a limited number of interviews and may be underestimated. Source: DAWR unpub. data.*

| METHOD | SHORE BASED | | BOAT BASED | | TOTAL |
|---|---|---|---|---|---|
| | Harvest (kg) | CPUE (kg/ gr-hr) | Harvest (kg) | CPUE (kg/ gr-hr) | Harvest (kg) |
| Bottom* | | | 34,633 | 0.80 | **34,633** |
| Cast Net | 20,189 | 0.4451 | 1,745 | 2.60 | **21,934** |
| Snorkel Spear | 9,725 | 0.5771 | 5,804 | 0.82 | **15,529** |
| Hook and Line | 13,731 | 0.104 | | | **13,731** |
| Gill Net | 7,286 | 0.4677 | 3,227 | 5.66 | **10,513** |
| Trolling* | | | 6,204 | 2.00 | **6,204** |
| SCUBA Spear** | 1,209 | 1.7286 | 2,885 | 1.83 | **4,094** |
| Hooks and Gaffs | 2,473 | 0.3829 | | | **2,473** |
| Surround Net | 2,446 | 3.1972 | | | **2,446** |
| Atulai Jigging | | | 752 | 0.99 | **752** |
| Spincasting | | | 468 | 0.42 | **468** |
| Jigging | | | 360 | 1.10 | **360** |
| Aquarium Fish | | | 16 | 1.00 | **16** |
| Longline | | | 12 | 1.00 | **12** |
| Mix Spear | | | | | **0** |
| Drag Net | | | | | **0** |
| Other | 1097 | 0.5312 | | | **1,097** |
| Total | 58,156 | | 56,106 | | **114,262** |

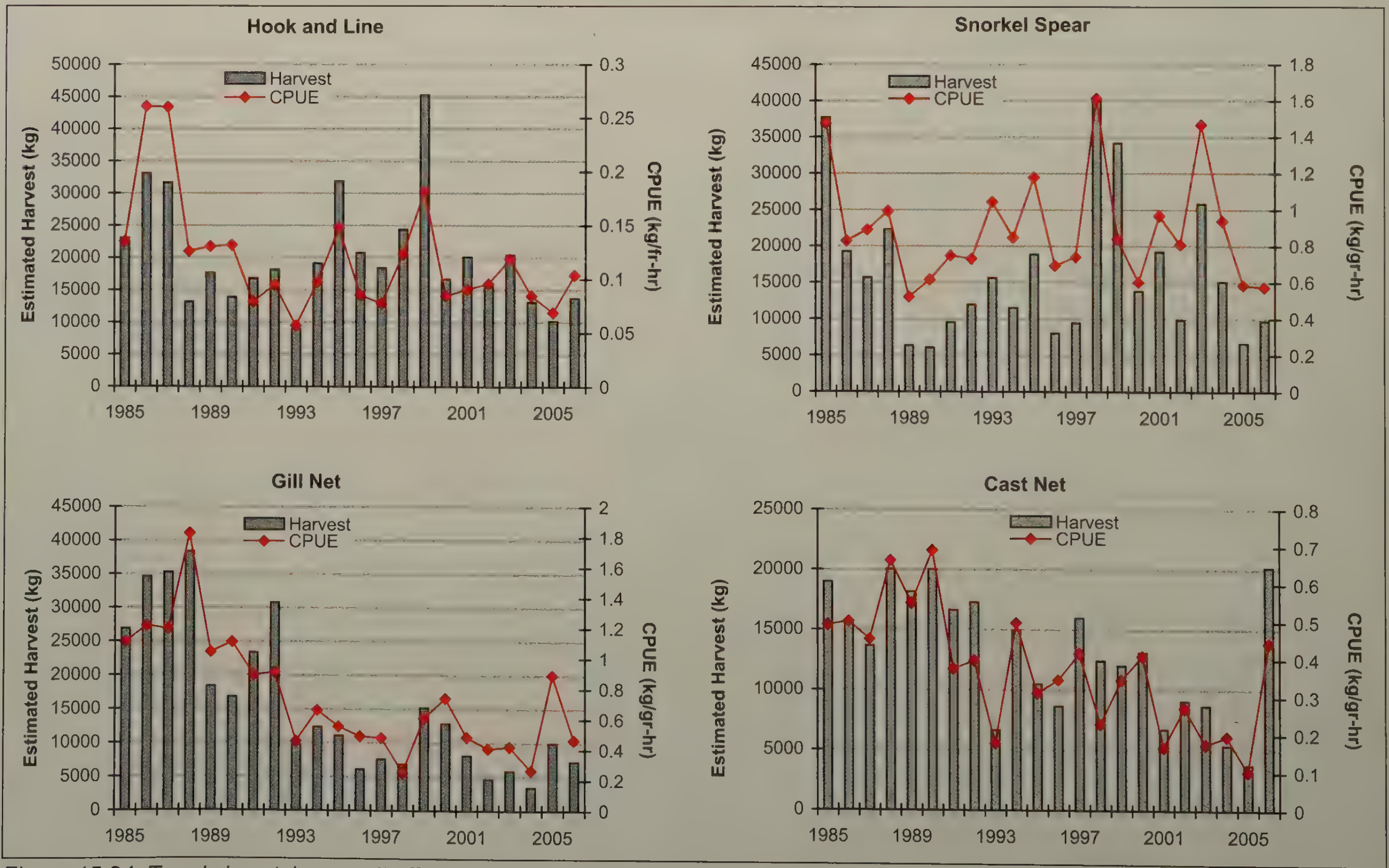


*Figure 15.24. Trends in catch per unit effort (kg harvested/gear-hour) and total estimated harvest (kg) from 1985 to 2006 for four of the common shore-based fishing methods: gill net, snorkel spear, cast net, and hook and line. The data are from the expanded estimates calculated by the WPacFIN database from the DAWR shore based survey data. Source: DAWR, unpub. data.*

*Results and Discussion*

The trends in catch per unit effort, total estimated harvest and total estimated effort from 1985 to 2006 for four of the common shore-based fishing methods (e.g., gill net, snorkel spear, cast net and hook and line) are illustrated in Figure 15.24. These graphs indicate that overall harvest and CPUE have declined over the last twenty years for all of these primary methods. Although hook and line is the major contributor to the total catch and is the most common method used by fishermen, it also has the lowest CPUE. Snorkel spear and gill net methods have the highest CPUE and are important contributors to total harvest, although the data indicate that gill net effort has declined.

According to DAWR's FY06 annual report, Guam's shore-based fish stocks may be overfished. This concern is based on historical catch data and information from long-time fishermen (Flores, 2006b). The estimated harvest for the top five families of reef fish caught using shore-based fishery methods over the last three years is presented in Table 15.6. Acanthuridae (surgeonfishes) and Carangidae (jacks) continue to be the top two families targeted by shore-based fisheries.

The estimated harvest of the top five marine invertebrate species harvested using shore-based fishing methods over the last three years is presented in Table 15.7. Octopus continues to be the most popular invertebrate species collected using shore-based fishing methods.

*Table 15.6. Estimated harvest for the top five families of reef fish caught using shore-based fishery methods over the last three years. Data exclude seasonal runs of juvenile siganids and bigeye scads. Source: DAWR, unpub. data.*

| **SHORE-BASED FISHERIES HARVEST** | | | | | |
|---|---|---|---|---|---|
| **2004** | | **2005** | | **2006** | |
| **FAMILY** | **HARVEST (kg)** | **FAMILY** | **HARVEST (kg)** | **FAMILY** | **HARVEST (kg)** |
| **Acanthuridae** (Surgeonfishes) | 10,315 | **Carangidae** (Jacks) | 8,657 | **Acanthuridae** (Surgeonfishes) | 13,010 |
| **Carangidae** (Jacks) | 6,395 | **Acanthuridae** (Surgeonfishes) | 5,522 | **Carangidae** (Jacks) | 10,339 |
| **Siganidae** (Rabbitfishes) | 4,242 | **Mullidae** (Goatfishes) | 4,142 | **Kyphosidae** (Rudderfishes) | 5,645 |
| **Mullidae** (Goatfishes) | 1,785 | **Siganidae** (Rabbitfishes) | 2,468 | **Mullidae** (Goatfishes) | 5,373 |
| **Lutjanidae** (Snappers) | 1,696 | **Lethrinidae** (Emperors) | 1,468 | **Siganidae** (Rabbitfishes) | 5,219 |

*Table 15.7. Estimated harvest of the top five marine invertebrate species harvested using shore-based fishing methods over the last three years. Source: DAWR, unpub. data.*

| **SHORE-BASED INVERTEBRATE HARVEST** | | | | | |
|---|---|---|---|---|---|
| **2004** | | **2005** | | **2006** | |
| **SPECIES** | **HARVEST (kg)** | **SPECIES** | **HARVEST (kg)** | **SPECIES** | **HARVEST (kg)** |
| *Octopus other* | 2,531 | *Octopus cyanea* | 4,255 | *Octopus other* | 1,619 |
| *Tripneustes gratilla* | 569 | *Octopus other* | 683 | *Octopus cyanea* | 1,081 |
| *Panulirus penicillatus* | 307 | *Trochus niloticus* | 556 | *Octopus ornatus* | 747 |
| *Octopus ornatus* | 399 | *Scylla serrata* | 574 | *Toxipneustes pileolus* | 927 |
| *Panulirus penicillatus* | 307 | *Trochus niloticus* | 556 | *Octopus ornatus* | 747 |
| *Octopus cyanea* | 117 | *Tripneustes gratilla* | 452 | *Parribacus antarcticus* | 463 |

## Boat-based Fisheries

*Methods*

The boat-based survey is conducted on eight randomly selected days each month and covers the three primary launching sites: Agana Boat Basin, Agat Marina and Merizo Pier. Agana, the busiest site, is surveyed two weekdays and two weekend days each month, while Agat and Merizo are each surveyed on one weekday and one weekend day each month. Surveys are conducted during two shifts [AM: 0500-1200 hours (Agana), 0530-1200 hours (Agat), 0600-1100 hours (Merizo); and PM: 1600-2400 hours]. At the start of each survey day, the AM surveyor starts a boat log for the site. Surveyors record boat identification, departure and return times and report fishing method information on this log. The log is used to keep track of participation during the survey day and is the main priority for the surveyors. During the survey period, all returning vessels are approached and asked to provide information about their trip. Their participation is voluntary and surveyors are trained to get as much information as possible in the time available. Information collected includes: fishing method, number of fish, length of fish, fish species, amount of time spent fishing, gear used, area fished and meteorological/ocean conditions. In addition, a vehicle-trailer census is conducted during the shore-based participation survey, in order to record participation at all other sites around the island. The information from all three surveys is entered into the WPacFIN database, checked for quality, and then expanded to determine total effort and harvest for the entire island.

*Results and Discussion*

The trends in CPUE and total estimated harvest in kilograms for four of the common boat-based fishing methods, including bottom fishing, SCUBA spear, snorkel spear and gill net, are depicted in Figure 15.25 and Table 15.8. These graphs indicate that overall harvest and CPUE have declined over the last twenty years for most of these primary methods. Bottomfishing is the most popular boat based method targeting reef fisheries. The CPUE for this method has declined over the period from 1982-2006. In addition, the numbers of trips and fishermen in the fishery have declined over the last five years, possibly due to poor catch rates or fuel costs (Flores, 2006a). Despite the decline in effort, the CPUE for bottomfishing has increased slightly over the last five years.

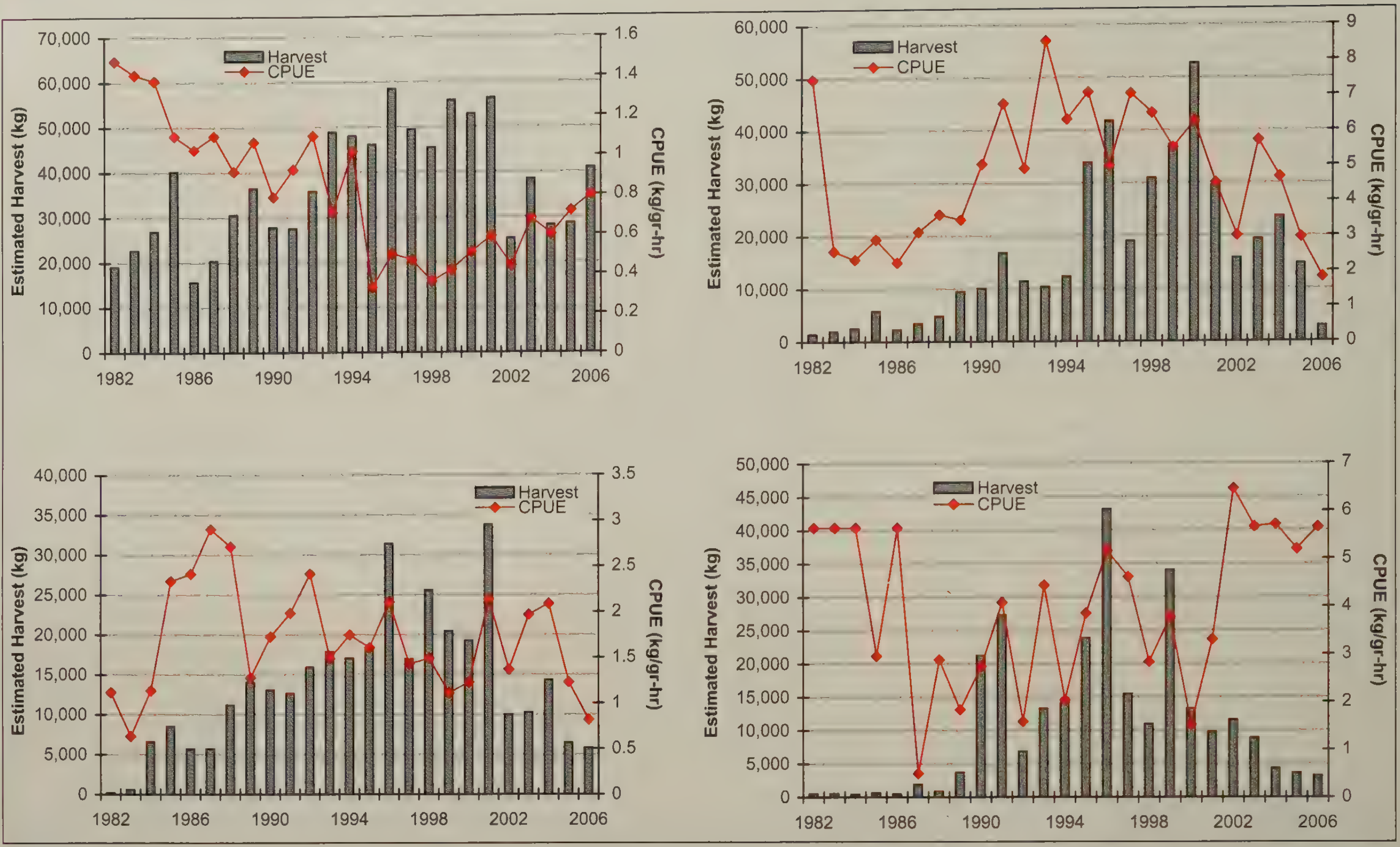


*Figure 15.25. Trends in catch per unit effort (kg harvested/gear-hour) and total estimated harvest (kg) for four of the common boat-based fishing methods: bottom fshing, SCUBA, spear, snorkel spear and gill net. The data are from the expanded estimates calculated by the WPacFIN database from the DAWR boat based survey data. Source: DAWR, unpub. data.*

Another popular method is spearfishing using SCUBA. This method became a major fishery in the 1990s. During this time, the catch regularly consisted of large grouper, wrasse and parrotfish and the CPUE was very high, approaching 9 kg per gear-hour in 1993. DAWR has documented a recent shift from these large species to smaller, faster growing species such as surgeonfish. According to the database, the CPUE for this method has greatly decreased over the last five years; it is important to note, however, that many of the fishermen using this method have refused to participate in the surveys. This prohibits the accurate documentation of this fishery, and DAWR expects that the values are underestimated (Flores, 2006a). Snorkel spear and gill net methods are the two other most popular methods targeting reef fish. Harvest and CPUE using these methods have decreased over the last five years. Gill net has consistently had the highest CPUE for all of the boat-based methods over the past five years (five year average=6.7), raising concerns about the sustainability of this method (Flores, 2006a).

The estimated harvest for the top five families of reef fish caught using boat-based fishery methods over the last three years is presented in Table 15.8. The top five families have changed, but there is no clear

*Table 15.8. Estimated harvest for the top five families of reef fish caught using boat-based fishery methods over the last three years. Source: DAWR, unpub. data.*

| BOAT-BASED FISHERIES HARVEST | | | | | |
|---|---|---|---|---|---|
| 2004 | | 2005 | | 2006 | |
| FAMILY | HARVEST (kg) | FAMILY | HARVEST (kg) | FAMILY | HARVEST (kg) |
| **Acanthuridae** (Surgeonfishes) | 18,751 | **Lutjanidae** (Snappers) | 13,062 | **Lutjanidae** (Snappers) | 9,668 |
| **Carangidae** (Jacks) | 18,247 | **Acanthuridae** (Surgeonfishes) | 8,481 | **Carangidae** (Jacks) | 11,193 |
| **Lutjanidae** (Snappers) | 10,925 | **Carangidae** (Jacks) | 8,319 | **Scombridae** (Mackerels) | 6,360 |
| **Lethrinidae** (Emperors) | 8,974 | **Lethrinidae** (Emperors) | 5,446 | **Sphyraenidae** (Barracudas) | 5,257 |
| **Scaridae** (Parrotfishes) | 8,603 | **Scaridae** (Parrotfishes) | 3,954 | **Lethrinidae** (Emperors) | 4,804 |

*Table 15.9. Estimated harvest (in kg) of the top five marine invertebrate species harvested using boat-based fishing methods from 2004-2006. Source: DAWR, unpub. data.*

| BOAT-BASED INVERTEBRATE HARVEST | | | | | |
|---|---|---|---|---|---|
| 2004 | | 2005 | | 2006 | |
| SPECIES | kg | SPECIES | kg | SPECIES | kg |
| *Trochus niloticus* | 1,711 | *Octopus cyanea* | 113 | *Trochus niloticus* | 2,139 |
| *Panulirus penicillatus* | 132 | *Panulirus versicolor* | 27 | *Octopus cyanea* | 423 |
| *Octopus teuthoides* | 103 | *Parribacus antarcticus* | 12 | *Panulirus penicillatus* | 205 |
| *Lambis truncata* | 87 | -- | -- | *Octopus ornatus* | 13 |
| *Sepioteuthis lessoniana* | 65 | -- | -- | *Parribacus antarcticus* | 10 |

trend. Top families have included the Lethrinidae (emperors), Acanthuridae (surgeonfish) and Lutjanidae (snappers).

The estimated harvest of the top five marine invertebrate species harvested using boat-based fishing methods are provided in Table 15.9. *Trochus* was the most popular invertebrate species for four of the last five years. Octopus and lobster species also contributed regularly to the boat-based invertebrate harvest. *Trochus* and lobster are primarily harvested using SCUBA. Due to the low level of survey participation by fishermen using SCUBA, the estimated harvest values for these species are probably underestimated (T. Flores, pers. comm.).

## *UOGML Long-term Monitoring Program: Fish Communities*

Fish communities were surveyed in 2006 along permanent transects established for the UOGML's long-term monitoring program. Detailed information about site selection and the establishment of permanent transects at each site is provided in this report.

### *Methods*

At each transect, species from 11 fish families (Serranidae, Lutjanidae, Lethrinidae, Nemipteridae, Mullidae, Chaetodontidae, Pomacanthidae, Labridae, Scaridae, Siganidae and Acanthuridae) were counted in a 5 m wide band (2.5 m either side of the transect center line). In order to minimize disturbance to the fish, the counts took place as the observer laid each 50 m tape. The same observer returned along the transect and counted all species of Pomacentridae in a 1 m wide band.

### *Results and Discussion*

A summary of the total abundance of each fish family based on the limited baseline data reveals similar patterns across all five sites, despite one site's (Tumon Bay) marine preserve status (Figure 15.26). The most abundant family (numerical abundance) is Pomacentridae followed by the Acanthuridae and Scaridae. Interestingly, the families Lutjanidae and Lethrinidae, which include the popular food fish *Lethrinus harak* (Mafute), are poorly represented at all sites, although they are most abundant at Fouha Bay. The piscivorous fish in the family Serranidae, which are heavily targeted by fishermen, were completely absent from one of the five sites. The lack of rabbitfish (Siganidae) may have been a direct result of the position of the transects on the reef slope (average depth 5 m), which is not typical habitat for this family. Similarly, fish in the families Pomacanthidae and Mullidae were absent from all sites, with the exception of a few individuals from the Millidae family that were recorded at Fouha Bay. Four of the five sites were similar in terms of total fish species (presented as species richness). However, Pago Bay recorded nearly 50% fewer species than Double Reef, which is not surprising given it also had the lowest hard coral cover (Figure 15.27; Figure 15.18).

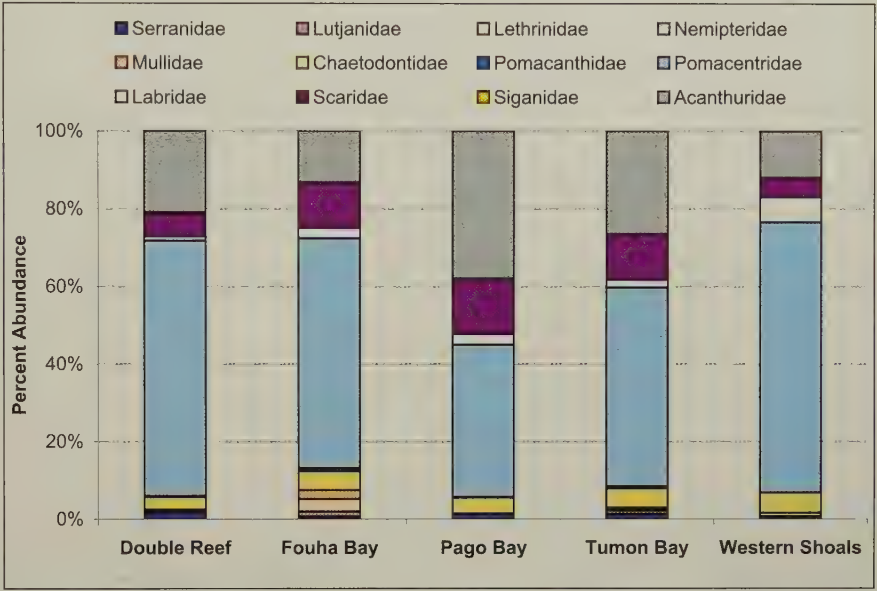


*Figure 15.26. Percent total abundance of each fish family five monitoring sites. Source: J. McIlwain, unpub. data.*

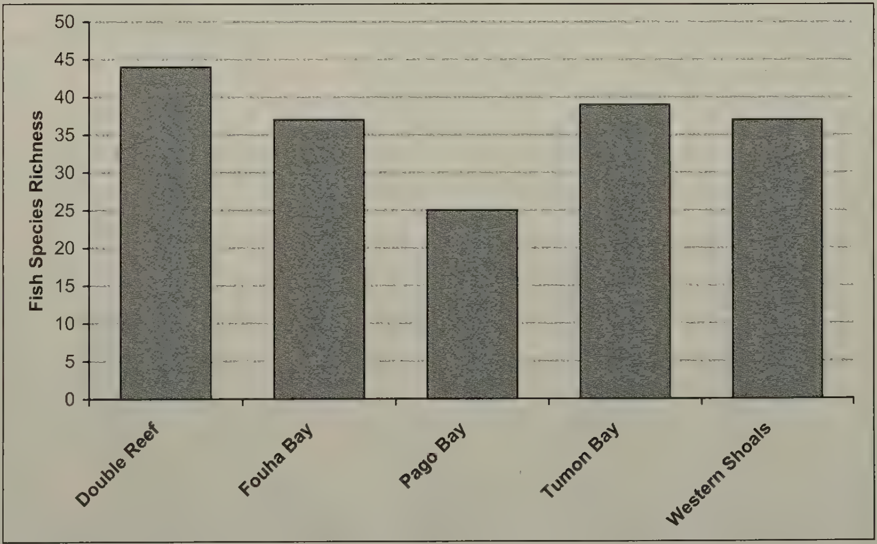


*Figure 15.27. Fish species richness at each site. Source: J. McIlwain, unpub. data.*

## *MARAMP Fish REAs and Towed-Diver Surveys*

### *Methods*

Fish were resurveyed by NOAA PIFSC-CRED from October 3-9, 2005, at the nine REA stations around Guam and two at Santa Rosa Bank (Figure 15.14). Quantitative belt transects, stationary point counts and towed-diver surveys were conducted at monitoring sites visited during the first PIFSC-CRED cruise in 2003, using standard protocols summarized in Porter et al., 2005.

*Results and Discussion*

In general, fish diversity and abundance were relatively low around Guam, although both were slightly higher along the north and east shores, which are characterized by relatively good habitat rugosity and higher live coral cover. Medium-large fish (>25 cm)were very rare along the leeward (west) side of the island. Sharks were rare; only one white-tip and one black-tip were seen. No Napoleon wrasse; most were (*Cheilinus undulatus*) or bumphead parrotfish (*Bolbometopon muricatum*) were observed. Slightly more fish were seen in the marine preserve areas (snappers, emperors, unicornfish, parrotfish, goatfish). The north side of Guam revealed a moderate diversity and abundance of medium-large fish (e.g., *Lethrinus xanthochilus*, *Caranx melampygus*, *Macolor niger*, *Aphareus furca*, *Kyphosus cinerascens*). Other taxa of medium-large size, such as parrotfish, *Lethrinus* spp. *Monotaxis grandoculis*, *Aprion virescens* and *Lutjanus* spp., were also of fair abundance. Other common taxa included wrasses, surgeonfish and rabbitfish. The most common fish found on belt transects along the west side of Guam were damselfish (*Pomacentrus vaiuli*, *Stegastes fasciolatus*), wrasse (*Halichoeres margaritaceus*, *Thalassoma quinquevittatum*) and surgeonfish (*Acanthurus nigrofuscus*, *Ctenochaetus striatus*). These same three families were also common along the north and east sides, while additional taxa (angelfish, butterflyfish, snappers, groupers and goatfish) were also better represented. Planktivorous damselfish were also more abundant at these sites (e.g., *Pomachromis guamensis*, *Chromis acares*, *C. vanderbilti*, *Dascyllus reticulatus*).

Large fish (>50 cm) biomass for both Guam and Santa Rosa Bank recorded during towed-diver surveys, was very low at around 0.01 ton ha$^{-1}$, compared to the 0.13 ton ha$^{-1}$ average for the "middle" Mariana Islands (Sarigan, Guguan, Alamagan, Pagan and Agrihan), and the 0.25 ton ha$^{-1}$ average for the "northern" islands (Asuncion, Maug, and Uracas; Figure 15.28). Medium to large fish (>25 cm) biomass was also very low around Guam compared to the rest of the Mariana Islands (0.1 ton ha$^{-1}$ versus 1.7 ton ha$^{-1}$; see CNMI chapter).

### MARAMP Macroinvertebrate Surveys

*Methods*

Conspicuous macroinvertebrates were recorded by towed-divers along 10-m wide transects at depths of 15-25 m during the 2005 and 2007 MARAMP expeditions. Echinoids, Holothuroids, COTS and *Tridacna* spp. (giant clams) were recorded at numerous sites around the island. Both Guam and Santa Rosa Bank were surveyed in 2005, while only Guam was surveyed in 2007.

*Results and Discussion*

Macroinvertebrates were in relatively low abundance around Guam, with the exception of high urchin and COTS densities at some sites (Figure 15.29). Echinoid abundance was generally low around the island, with the greatest abundances observed on the north-east corner of the island. COTS were observed in both 2005 (449 total observed, mean of 8.24 individuals/ha) and 2007 (648 total observed, mean of 14.60 individuals/ha). These numbers represent a 100% and 200% increase, respectively, over the number of COTS observed in 2003 (n=215). COTS outbreak densities were observed on 24 out of a total of 107 individual, five-minute tows (22%) in 2007, with densities greater than 100 individuals per hectare observed on seven of these tows (Figure 15.13). A further 28 tows (26%) exhibited moderately high densities of between 15-25 individuals per hectare. The highest COTS densities were found along the eastern coastline near Fadian Point and near Cocos Island during the 2007 cruise. Relatively high COTS densities were also observed at Ypao Pt, Nomna Pt, and north of Taguan Pt. As expected, high densities of COTS coincided with areas that exhibited high percentages of stressed coral. No COTS were observed on Santa Rosa Bank in 2005.

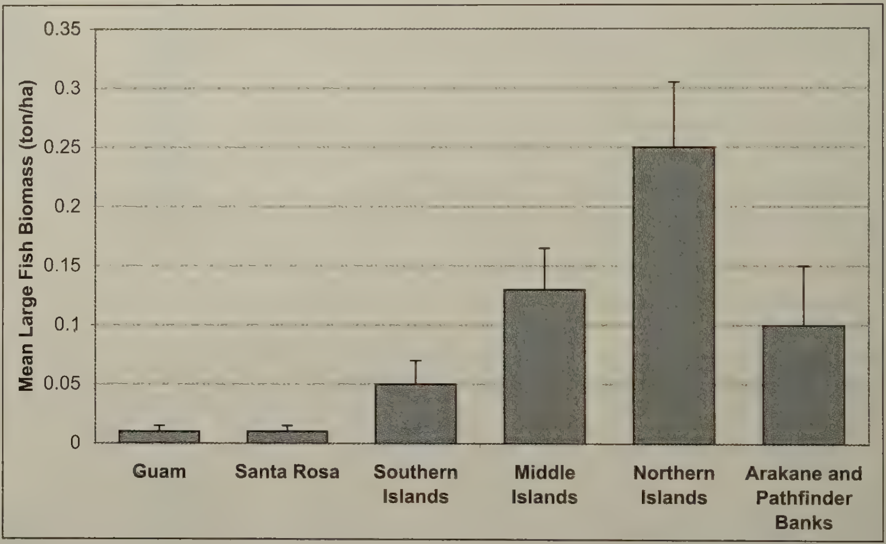


Figure 15.28. Large fish (TL >50 cm) biomass (tons/ha) measured on towed-diver surveys in the Mariana Islands. Source: PIFSC-CRED, unpub. data.

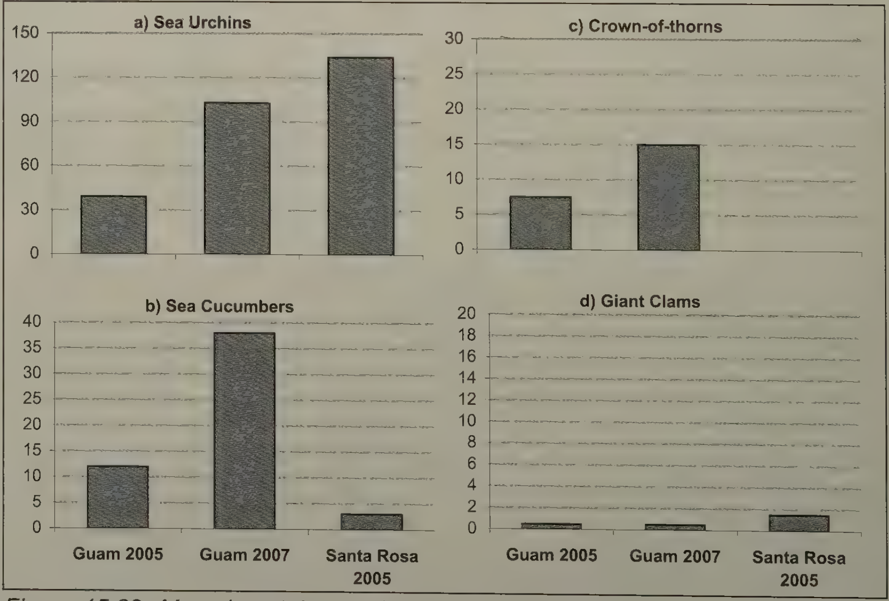


Figure 15.29. Macroinvertebrates (individuals/ha) observed around Guam (2005, 2007) and Santa Rosa Bank (2005). Source: NOAA PIFSC-CRED, unpub. data.

### The Role of Marine Protected Areas in Controlling Herbivory Levels and the Impact on Local Algal Communities (UOGML)

The goals of this study were to compare algal communities inside and outside marine preserves and test for any evidence of top-down effects as well as other differences in communities in terms of composition and abundance of algal species, including "bottom-up" effects caused by increased nutrient availability (Pioppi, in prep). Presented here are the preliminary results of the fish surveys conducted for this study. The final report for the overall study should be available in 2008.

*Methods*

Ten reef sites around Guam were surveyed monthly from January to December 2006. Five of these sites have no fishing restrictions; the remaining five sites prohibit most or all fishing according to Guam law and, in one case (Ritidian Point), federal law. Five pairs of protected/non-protected sites were chosen based on proximity, and members of pairs were surveyed on consecutive days. The pairs included (protected/unprotected): Piti/Asan, Tumon South/Agana, Tumon North/Tanguisson, Ritidian Closed (East Side)/Ritidian Open (West Side) and Achang/Chubic Beach. At each site, two permanent 50 m transects were installed on the reef flat parallel to the shoreline. Transects at each site were surveyed consecutively, starting with the same transect each sampling period. At the beginning of each survey, a 50 x 5 m fish count with size estimations was performed for target species in the following families: Acanthuridae, Scaridae and Siganidae. Benthic cover was estimated every five meters along each transect using a 16-point quadrat count method. Macroalgae were identified to species when possible; other categories recorded included sand, cyanobacteria and crustose coralline algae. Environmental data, such as temperature and water height, were also collected.

*Results and Discussion*

Mean adult (>6 cm) abundance for fish from the families Scaridae and Acanthuridae for each pair of protected and non-protected sites is provided in Figure 15.30. These preliminary data indicate that the protected sites tended to have a greater abundance of these families than in the non-protected sites. The greater abundance of Scaridae in protected sites is clearly evident in four of the five site pairs, even given the relatively high degree of seasonal variation in abundance observed at most sites. While monthly counts of Acanthuridae were consistently higher for most protected sites compared to non-protected sites, the high variation of seasonal abundance observed at most sites tended to obscure differences between protected and non-protected sites. Comparative statistical analysis will be performed on both the fish and the algal data; multivariate ordination techniques will be used to examine the effect of herbivorous fish on algae community structure and percent cover.

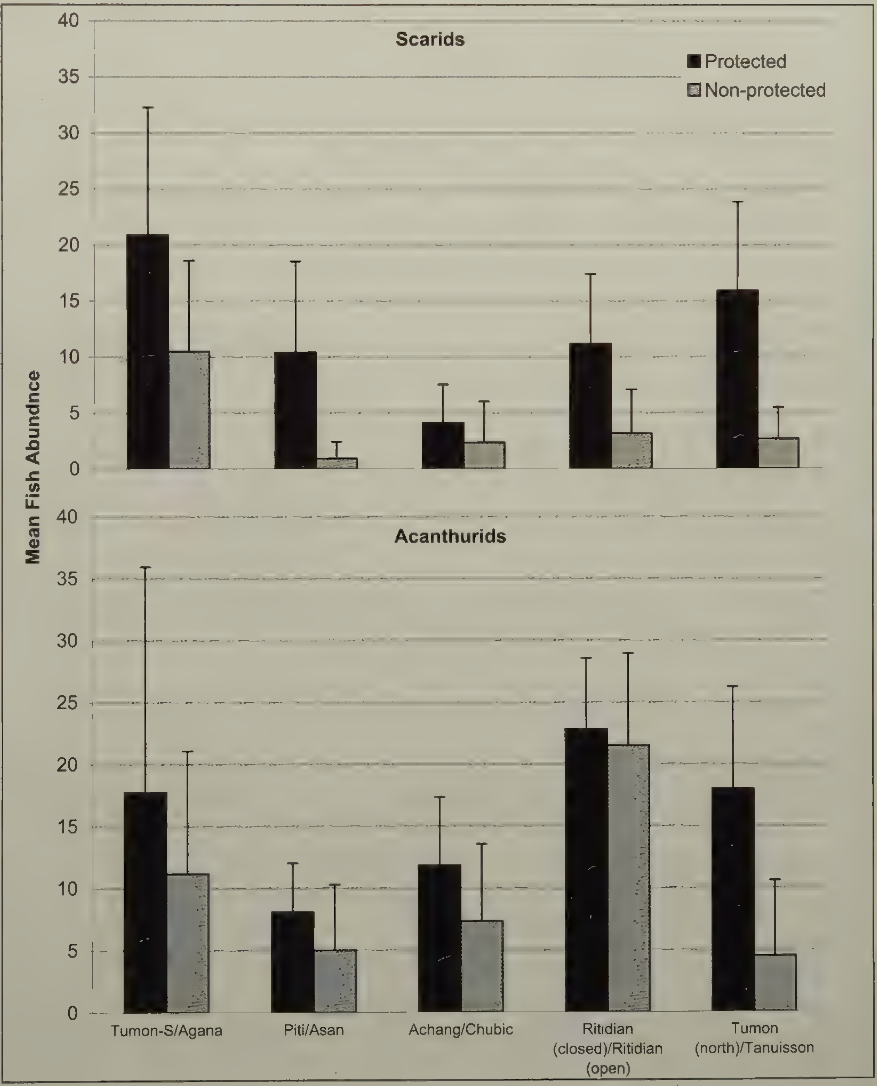


*Figure 15.30. Mean adult (>6 cm) abundance (± SD) of fish in the families Scaridae and Acanthuridae observed in protected and non-protected areas between January and December 2006 (n=12). Source: N. Pioppi, unpub. data.*

### Impacts of Fishing on Coral Reef Resources in the War in the Pacific National Historic Park

In 2005, researchers from the UOGML examined the impacts of fishing on the coral reef resources in the WAPA (Tupper and Donaldson, 2005). The investigation had several objectives, including: 1) determining the spatial and temporal pattern of fishing in park waters; 2) identifying the species exploited in the fishery; 3) determining the CPUE of different fishing methods; and 4) conducting population assessments of key fishery species within the park and comparing no-take marine protected areas (e.g., Piti Bomb Holes Preserve) to adjacent areas open to fishing.

*Methods*

Effort-hours, number of fish landed, mean length of fish landed and CPUE were obtained through interviews with 63 fishers at six locations within the park. *In situ* fish surveys were also conducted; live fish biomass was estimated by visual estimation of total length and abundance along 50 x 5 m transects. Four replicate transects were surveyed at Piti Bomb Holes Marine Preserve and Asan Bay sites. Published length-weight regressions for each species were applied to length and abundance data to estimate biomass for each species.

*Results and Discussion*

Fish biomass was significantly higher within the Marine Preserve than in Asan Bay (one-way ANOVA, $p<0.01$ for all species except *Acanthurus triostegus* (Figure 15.31), indicating that the preserve is producing more and larger fish than the adjacent exploited area of Asan Bay. Most fishing effort (measured in effort-hours) involved either rod and reel (75 hours) or sling (59 hours), followed by gill net, cast net, straight spear and spear gun (Table 15.10). Slings landed the greatest number of fish, followed by rod and reel. However, cast nets exhibited the highest CPUE, followed by gill net, sling, rod and reel, and straight spear. No catch was reported by fishers using spear guns from the shore. The researchers concluded that WAPA is subject to considerable fishing pressure, evidenced by the lower biomass of nine out of 10 common reef fishes in the exploited Asan Bay as compared to the adjacent marine preserve. The heavy fishing pressure also results in degradation of the reef through discarded gear and trampling of corals, but further research is needed to determine the extent of physical impacts of fishing on the park's submerged resources.

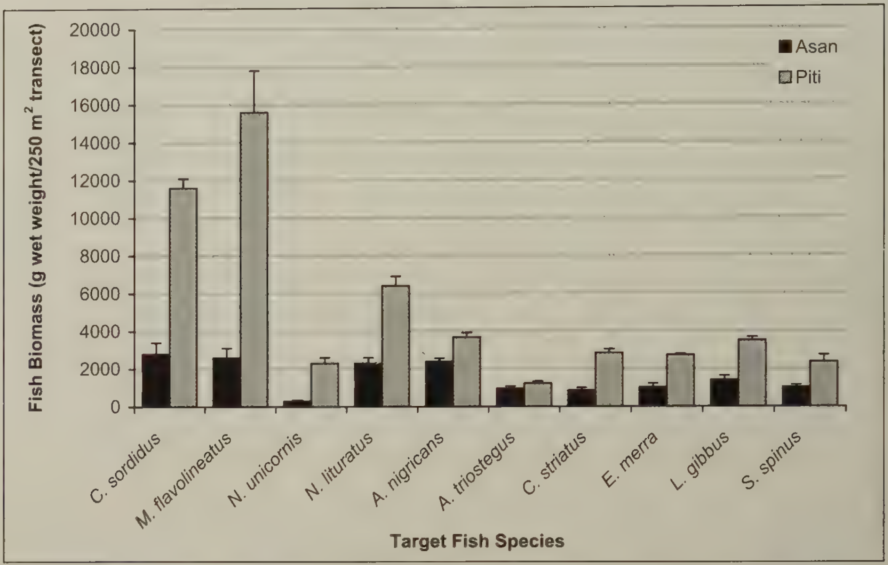


*Figure 15.31. Mean biomass (± 1 SD) in grams of reef fishes in exploited versus protected areas of WAPA. Source: modified from Tupper and Donaldson, 2005.*

*Table 15.10. Number of fishers, numbers of fish caught, mean fish length, hours of effort and CPUE from creel surveys at WAPA. Source: modified from Tupper and Donaldson, 2005.*

| Gear Type | Number of Fishers | Number of Fish | Mean Total Length (cm) | Effort (hrs) | CPUE |
|---|---|---|---|---|---|
| Cast net | 6 | 53 | 16.8 | 11.5 | 4.61 |
| Gill net | 8 | 67 | 9.9 | 19.5 | 3.44 |
| Sling | 6 | 139 | 12.4 | 59 | 2.36 |
| Rod & reel | 34 | 116 | 20.7 | 75 | 1.55 |
| Straight spear | 6 | 3 | -- | 9.5 | 0.32 |
| Spear gun | 3 | 0 | -- | 2.5 | 0 |

### Sociological and Economic Monitoring Activities

The importance of sociological and economic assessment and monitoring activities in effective management strategies is becoming more widely recognized. The causes of coral reef degradation and the solutions necessary to reverse these trends are often, at their root, economic and social in nature. The lack of sociological studies in the past has limited the effectiveness of coral reef management activities, as the relationship between humans and the reef, and the motivations for particular detrimental or beneficial behaviors, are not fully understood or are disregarded. The lack of economic assessments, such as coral reef valuation studies, has lead to underestimations of the economic and cultural importance of coral reefs. As a result, short-term economic gains from destructive activities are often pursued over more sustainable economic activities that are considerably more profitable in the long-term.

An earlier attempt to value the ecological services, tourist-related industries and coastal protection from Guam's reefs concluded that the island's reefs were worth $85 million a year (Richmond, 2000). Although this study was an important step in the direction of valuing the economic importance of Guam's reefs, it was limited by its use of secondary data sources and its exclusion of the cultural importance of reefs, which can be expressed in monetary terms. A comprehensive study was conducted in 2005-2006 to determine the economic value of Guam's coral reefs and associated resources by collecting primary data and incorporating cultural value through special survey methods. Another study evaluated the effectiveness of GCMP's various public outreach activities and identified the environmental issues of most concern to the public.

### Guam Coral Reef Economic Valuation Study

In 2005-2006, an international team of researchers contracted by the UOGML carried out a comprehensive economic valuation of the coral reefs and associated resources of Guam (van Beukering et al., 2007). The aim of the study was to provide much-needed information about the economic importance of Guam's reefs, allowing decision makers to formulate more effective policies utilizing limited funds. The study assessed the value of five main coral reef uses on Guam: 1) extractive uses, such as fisheries; 2) non-extractive uses, such as recreation/tourism; 3) cultural/traditional uses; 4) education; and 5) research indirect uses, such as shoreline and infrastructure protection. In addition to estimating the total economic value, the researchers also investigated the underlying motives and mechanisms behind the total economic value by focusing on people's relationship with the marine ecosystems, local "willingness to pay" (WTP) for coral reef conservation and the spatial variation of reef-associated economic values and threats.

### *Methods*

The researchers gathered existing data from a variety of sources, including tourist exit surveys, real estate databases, and DAWR creel surveys. To supplement these data, they conducted a household survey of 400 Guam residents to assess the cultural value of coral reefs. For households that fish, a supplemental survey about fishing was conducted. At the end of the survey, the researchers conducted a Discrete Choice Experiment (DCE) to determine individuals WTP for services that do not have market values. These data were analyzed to determine the total economic value of Guam's reefs, representing the entire economic importance of Guam's marine environment. The researchers used a variety of techniques to determine the value of six uses: tourism, diving and snorkeling, fishing, amenity value, coastal protection and biodiversity; they also used Geographic Information System tools to determine the spatial variation of reef-associated economic values and threats.

### *Results and Discussion*

#### Household Survey

The results of the survey indicated that several recreational activities link local residents to marine ecosystems. Over 92% of the population uses Guam's nearshore resources such as beaches and reef flats for recreational activities. According to the survey results, fishing has not declined in popularity (between 35% and 45% of respondents were active fishermen) despite depleted fish stocks. The survey found that the majority of fishermen fished because they enjoyed it and because it strengthens social bonds. Despite external influences, freshly-caught fish is still an essential part of local diets. At the time of the study, more than half of all consumed fish was obtained from stores and restaurants, while about 40% came from immediate or extended family or friends. Fishermen spent around $165 a month to fish; only a small number of fishermen on Guam sell part of their catch, indicating that fishing in Guam is neither a subsistence, nor a commercial, activity. The survey showed that most local residents have witnessed a degradation of the marine environment in recent decades, with declines in water quality and fish abundance being the most cited concerns. Residents identified increased runoff, poor development practices and leakage from broken sewage pipes as the three main causes. Residents were also asked for solutions and suggested improvements to the sewer system, increased environmental education and stricter law enforcement.

#### Discrete Choice Experiment

The results of the DCE indicate that significant economic values are associated with three non-market benefits evaluated in the survey: local recreational use, abundance of culturally significant fish species, and noncommercial fishery values. Guam's residents appeared to place a similar value on the reefs' ability to provide local recreational benefits and supply culturally significant fish species. The results also indicated that maintaining reef fish and seafood stocks at a level that can support the culture of food sharing was very important. Interestingly, the DCE revealed that WTP for fish catches sufficient to share with family and friends was nearly triple the WTP for a catch large enough for the sale of fish ($92 versus $32), implying that the sharing of fish was more important than earning additional income. The DCE also revealed residents' attitudes towards management. Guam's residents generally supported a ban on some of the more exploitative fishing methods (e.g., night SCUBA spear fishing), but they were more concerned about managing the threat of pollution. The concern about pollution revealed in the DCE is not surprising considering pollution negatively affects both fishing and recreational beach uses, which were identified as two of the most important reef-related activities for Guam's residents.

#### Total Economic Value (TEV)

The researchers determined that the TEV of Guam's reefs is between $85-164 million/year with a core value of $127 million/year. Table 15.11 shows the breakdown by type of reef-related value. The tourism industry in general accounts for nearly three-quarters (74%) of the TEV, followed by amenity (e.g., property values) at 7.5% and diving and snorkeling at 6.8%. As is expected for a tourism-dependent island economy, the market value of the fishery sector (3.1%) is almost negligible compared to the value provided by non-consumptive goods and services.

*Table 15.11. Total economic value of coral reefs in Guam. Source: modified from van Beukering et al., 2007.*

| TYPE OF REEF-RELATED VALUE | ECONOMIC VALUE (MILLION $/YEAR) | ECONOMIC VALUE (% OF TOTAL) |
|---|---|---|
| Tourism | 94.63 | 74.30% |
| Amenity | 9.6 | 7.50% |
| Diving and snorkeling | 8.69 | 6.80% |
| Coastal protection | 8.4 | 6.60% |
| Fishery | 3.96 | 3.10% |
| Biodiversity | 2 | 1.60% |
| **Total Economic Value : $127.28 million/year** | | |

#### Spatial Variation Analysis

A map of TEV was developed by aggregating individual maps of fisheries, tourism, recreation, amenity, biodiversity and coastal protection. The average value per square kilometer was $2 million/year, with the highest value area valued at nearly $15 million/year. The highest value reef area measures only 200 m$^2$, and is host to the most popular diving and snorkeling sites. A threat map was developed by aggregating maps of various threats, including sedimentation, eutrophication, freshwater runoff, overharvest and tourist overuse to build a map depicting the spatial variation in threats to Guam's reefs.

The results of the spatial analysis indicated that the most economically valuable reefs are, typically, the most threatened. The most valuable reefs are located within 200 m of the most popular diving and snorkeling spots. Corals adjacent to tourism areas in Tumon, Agana and Piti are also valuable due to their high level of use. Reefs in the southern part of the island have relatively high value due to tourism use, but are highly threatened due to sedimentation. The northern reefs are in better condition, but besides a few exceptions, their value is relatively low.

While the study helped identify the most valuable and most threatened reefs on Guam, and to some degree identified the type of threats endangering specific reefs, the authors suggest that, in order to provide the most economically-sound guidance to reef managers and policy-makers, the benefits and costs of various management interventions must be evaluated and sustainable sources of funding for these actions must be identified. Still, they were able to provide several policy recommendations based on the outcomes of the study, including: 1) making use of the cultural importance residents place on marine ecosystems to improve coral reef management; 2) actively involving the tourism industry in the development of sustainable coral reef management; 3) limiting the commercial consumptive use of coral reefs by prioritizing stronger enforcement of marine protected areas in Guam; and 4) prioritizing potential policy interventions in an economically sound manner.

### *Guam Coastal Management Program Outreach Effectiveness/Public Issue Priority Assessment*

The GCMP contracted QMark Research and Polling in 2005 to conduct a quantitative study with Guam residents to evaluate the effectiveness of the Program's various public outreach activities and to identify the environmental issues of most concern to the public (QMark Research and Polling, 2005). This study, which involved 387 telephone interviews conducted in August 2005, was one of the more comprehensive assessments of public awareness concerning environmental issues on Guam.

The results of the survey indicated that a large majority (88%) of respondents considered the island's environment and natural resources a very important part of their lives. When asked to identify the level of responsibility that residents should bear in preserving Guam's natural environment, a majority (81%) agreed that they shared a large responsibility in the preservation and upkeep of Guam's natural environment. The local government and the community-at-large were identified as the two primary partners in the protection of the local environment. A majority of respondents indicated that trash/landfill issues are of primary concern, with concerns about drinking water quality/supply and pollution ranking a distant second and third, respectively. Interestingly, coral reef/marine issues and ocean/coastlines issues were not of great concern compared to trash/landfill, water quality/supply and pollution; this could be a result of the relatively high percentage of residents who don't snorkel or SCUBA dive and may not be aware of the deteriorating state of some of Guam's reefs. The results suggest that future outreach activities should focus on informing citizens not only of the importance of Guam's reefs, but also about the poor condition of parts of the reef ecosystem.

The study also provided an opportunity to identify the primary sources of environmental-related information for Guam residents. The responses indicated that the Pacific Daily News, a local newspaper, and KUAM, a local television station, are the primary sources of environmental information for the largest number of respondents (89% and 78%, respectively), while 38% of the respondents obtained environmental-related information from GCMP's Man, Land and Sea television show or newsletter. The annual International Coastal Cleanup and Island Pride events (e.g., an annual festival, cleanups, other events) were also a source of information for approximately a quarter of the respondents.

The researchers also sought to identify incentives preferred by residents for participating in the conservation of Guam's natural resources. New laws with penalties for violations were cited most often as a policy that would get residents to more actively participate in the care and upkeep of Guam's environment. About half of respondents felt that in-home demonstrations and having children asking adults to behave in a certain manner would be a successful strategy.

#### *Overall Condition/ Summary of Analytical Results*

The health of Guam's reefs remains highly variable, with some reefs showing signs of degradation due to multiple stressors and others supporting diverse, relatively healthy reef communities. Since long-term monitoring efforts have only recently begun, it is difficult to objectively assess the health of Guam's reefs. However, it is clear from the data presented in this report that the stressors affecting Guam's reefs have increased and are likely to continue to increase in the future. Poor water quality, the paucity of large herbivorous fish and low coral recruitment may severely decrease the resiliency of Guam's reefs to recover from future disturbance events. With this in mind, reefs described in this section as "healthy" should be considered so only relative to other, more degraded reefs on Guam, and relative to reefs of the past few decades as described by relatively limited data sets.

The data presented in this report suggest that the overall scarcity of reef fish, especially larger individuals, despite the persistence of some relatively healthy and diverse coral communities, continues to be a serious concern (Schroeder et al., 2006). The abundance of medium-to-large fish on Guam and Santa Rosa Bank rank as the lowest in the archipelago and are also quite low compared to other islands in the U.S. Pacific. In contrast, fish abundance has increased significantly in Guam's Marine Preserves (Gutierrez, 2003). Recent studies further demonstrate the effectiveness of the marine preserves in maintaining consistently greater target fish abundance than unprotected areas, and other ongoing studies appear to indicate adult fish and larvae are exported from the preserves to nearby reefs, potentially enhancing fish catches in these areas (Tupper, in prep). In addition, coral disease, bleaching and COTS outbreaks have emerged as more serious threats since the last report in 2005. Coral diseases have been documented across the island's reefs, minor to moderate bleaching has affected the shallow reef systems twice, and COTS populations have bloomed. Still, these threats do not affect all of Guam's reefs and a broad range of reef conditions have been documented.

The northern reefs are generally considered to be in better condition than reefs in the south, and although they may be exposed to elevated nutrient levels through groundwater discharge, northern reefs are not affected by the intense levels of sedimentation experienced by many southern reefs. In general, the highest coral cover and diversity on Guam is found in an area beginning roughly at Falcona Beach on the northwest coast, continuing clockwise around the northern coast, and extending down to Pagat Point on the eastern side of the island. The abundance of medium-to-large fish is slightly higher on northern reefs compared to reefs in other parts of the island, possibly due to the relatively better habitat quality and restricted fishing access. COTS outbreaks may have significantly altered the coral communities in the northwestern part of the island in the last few years, including at least some of the reef extending north from Falcona Beach to Ritidian Point. The reef tract between Tanguisson Point and Falcona Beach, which was also reported to have high coral cover and diversity (Porter et al., 2005), has since been the site of the largest COTS densities recorded in the last few years (approximately 1,500 individuals/ha; C. Caballes, unpub. data).

The health of reefs along the central and southern portions of the east coast is highly variable; some reefs adjacent to large river mouths have been degraded by sedimentation and freshwater runoff, while other reefs appear relatively healthy. Some of the areas in the east-central and southeastern part of the island reported as relatively healthy in Porter et al. (2005), including the fore reef slope off Achang Reef Flat Marine Preserve and the south side of Cocos Lagoon, have since experienced outbreak densities of COTS. Other areas previously known to have relatively high coral cover and diversity, such as near the UOGML in the northern part of Pago Bay and at sites south of Agfayan Bay and south of Talofofo Bay, have also been heavily impacted by COTS predation.

Although Apra Harbor is home to the busiest port in Micronesia, a large U.S. Navy base, and numerous recreational facilities, it contains both patch and fringing reefs with some of the highest coral cover (>80%) on the island. The reefs along the northern side of the peninsula and the many patch reefs and shoals throughout the harbor provide habitat for a significant number of invertebrate species and are an important foraging area for resident sea turtles. Coral growth along the south side of Orote Peninsula is limited, with much of the reef comprised of turf and macroalgae-dominated pavement scattered with small coral colonies. While the harbor reefs appear to be doing relatively well, the impacts of the increased turbidity, pollution, and invasive species associated with the area's use as a port and naval base have not been fully assessed. Approximately 1.2 ha (3 acres) of patch reef were removed from the entrance of the Inner Harbor by the Navy in 2006 and 2007 in order to meet the operational needs of the base. Additional areas are expected to be lost or degraded due to other planned construction and dredging activities in the harbor.

Most of the fringing reefs and patch reefs along the southwestern shore remain in poor to fair condition, depending on their proximity to river mouths. MARAMP benthic towed-diver surveys conducted in 2005 suggest that these reefs had the lowest average coral cover on the island. This is supported by the REA and UOGML data from this region. A 10 km stretch of reef in this area was heavily impacted by sedimentation from a poorly planned coastal road project in the early 1990s; the reefs continue to experience high levels of sedimentation from erosion caused by wildland arson, off road vehicle use and other activities.

Several large bays, including Piti, Asan, West and East Agana, and Tumon, are located along the central western coastline. This area generally experiences calm conditions for most of the year and is readily accessed by fishermen and other recreational users. Both Piti and Tumon Bays host a wide diversity of habitats, and possess areas with vibrant reef communities. Since their designation as marine preserves in 2001, fish abundance within the bays has increased significantly. The increase in herbivorous fish densities appears to have better controlled the growth of palatable macroalgae in the two preserves, resulting in healthier looking reefs (T. Leberer, pers. obs.). Asan Bay is heavily impacted by fishing, with fish stocks decreasing in this area since monitoring began in 2001. The reef communities in Asan Bay are also heavily impacted by sediment- and nutrient-laden river and stormwater discharges. The health of coral communities in West and East Agana Bays varies; coral cover is relatively high, especially along the shallow reef front and deeper fore reef slope, but fish abundance is low.

## CURRENT CONSERVATION MANAGEMENT ACTIVITIES

A broad network of agencies, educational/research institutions and organizations continue to carry out a range of activities aimed at mitigating the threats to Guam's coral reefs, improving public awareness of coral reef issues and monitoring the vitality of Guam's coral reef resources. Progress towards short- and long-term increases in human capacity to effectively carry out these activities has been made with the establishment of two scholarship programs for graduate study in marine biology/natural resource management, the NOAA Coral Management Fellowship, the Pacific Islands Technical Assistantship program, the NOAA Pacific Islands Regional Office (PIRO) Guam Field Office and various training opportunities for managers, technicians and teachers.

The goals and objectives of the various coral reef management projects on Guam are linked to the goals of the U.S. National Action Plan to Conserve Coral Reefs (2000) through locally-driven priorities enabled by the Local Action Strategy Initiative. In 2002, the Guam Coral Reef Initiative Coordinating Committee (GCRICC) identified the top five priority threats impacting Guam's coral reefs: land-based sources of pollution, overfishing, lack of public awareness, recreational misuse and overuse and climate change/coral beaching/disease. By 2003, LAS were drafted to address each of these priority areas. The five priority focus areas of the first round of LAS will continue into the next three-year LAS cycle. An additional LAS is currently being developed to address the impacts of the military expansion.

### Land-Based Sources of Pollution LAS

*Current Management Activities*
**Land-based Sources of Pollution**

- Federal approval of Guam's Nonpoint Source Pollution Control Program
- Re-vegetation efforts in Ugum and Fouha watersheds
- Extension of sewage outfalls at Hagatna and Northern STPs
- Adoption of Guam EPA Stormwater Management Manual
- Hiring of Arson Campaign Coordinator
- Hiring of consultant to develop management plan for Asan-Piti watershed
- Guam EPA's EMAP
- Wash-down facility and hazardous waste disposal containers at Agana Boat Basin
- Development of Seashore Reserve Plan

Land-based sources of pollution remain among the greatest threats to the vitality of Guam's coral reef ecosystem, and are perhaps the most challenging to address. Still, significant progress has been made in addressing this threat. The Watershed Planning Committee (WPC), comprised of representatives from local and federal agencies and NGOs, has continued in the development of a comprehensive watershed planning process to address pollution in each of Guam's watersheds. The committee previously developed restoration strategies for the Northern and Ugum priority watersheds and has since implemented restoration activities using a combination of federal (EPA, NOAA and U.S. Forest Service) and local funds and resources, as well as volunteer time. The development of a suite of measures to control nonpoint source pollution from watershed degradation, agriculture, development, marinas, and other sources led to the recent federal approval of Guam's Coastal Nonpoint Source Pollution Control Program, bringing Guam into compliance with the requirements of Section 6217 of the Coastal Zone Management Act Reauthorization Amendments of 1990.

Guam's Department of Agriculture's FSRD, the U.S. Department of Agriculture's Natural Resources Conservation Service (NRCS) and UOG are continuing work to restore grasslands and unvegetated areas (e.g., badlands) using erosion control fabric and nitrogen-fixing plants and trees such as Acacia. Between 2004 and 2005, approximately 52.6 ha (130 acres) of badlands and grasslands in the Ugum Watershed and the Coastal Conservation Reserve were converted to Acacia stands. Unfortunately, the success of these efforts is hindered by frequent wildfires and land ownership issues. The UOG, NPS, and the U.S. Navy are exploring the use of a variety of vetiver grass (e.g., *Vetiveria zizanoides*) as a means to reduce erosion in the southern watersheds. The watershed restoration efforts provide an opportunity for community members and groups to participate directly in the improvement of natural resources on Guam. Well over 1,500 volunteers have planted more than 75,000 trees in 86.6 ha (214 acres) since 2004. The NPS is also focusing attention on watershed restoration and erosion prevention with an investigation into how off-road vehicles impact native vegetation and contribute to the persistence on badlands within the park and a project to evaluate the effectiveness of techniques for restoring native grasslands and reducing soil erosion.

Guam's resource agencies are pursuing additional reforestation projects throughout the island. Currently planned projects include the Masso Reservoir restoration and the Piti Conservation Action Planning (CAP) project (discussed below). The local agencies, in coordination with the federal resource trustee agencies, are also working to facilitate the use of watershed restoration as mitigation for coral reef losses due to dredging and other development projects. The first of these mitigation plans is presented in the final EIS for the Kilo Wharf Expansion (Commander Navy Region Marianas, 2007).

The biggest challenge to watershed restoration efforts is the threat of wildland fires, most of which are set by poachers to promote the growth of young, tender plants preferred by deer. Wildland fire control efforts, which are also headed by the Guam Department of Agriculture, involve fuel reduction and the construction and maintenance of firebreaks and green breaks. During the dry season, the southern watersheds are patrolled and wildland fires are suppressed as effectively as possible. An arson campaign coordinator was hired by the FSRD in March 2007 to conduct outreach and education activities in an attempt to prevent illegal burning of natural grasslands.

Guam EPA has a number of permit processes in place to limit the impacts of nonpoint source pollution, including the Water Quality Certification (Federal Clean Water Act Section 401) and NPDES programs. Through its Water Pollution Control Program, Guam EPA is responsible for certifying all permit applications, recommending condition and abatement schedules for each permit, and providing oversight for the implementation of and compliance with the conditions. The Guam EPA also regulates the injection of stormwater runoff into dry wells in order to prevent contamination of groundwater and the pollution of nearshore marine waters through subsequent discharge. In 2006, Guam updated its *Guidance for Best Practices in the Preparation of Soil Erosion and Sediment Control Plan* and the *Storm Drainage Manual* into a combined *Stormwater Management Manual*. All developments larger than 0.4 ha (about one acre) are required to adhere to the manual, which establishes as best practices the reduction in impervious surfaces, the maintenance of natural drainage patterns, the preservation of vegetation, the control of 80% of total suspended solids and maintenance of post-development runoff rates equal to pre-development levels.

Major public works projects will also contribute to improved nearshore water quality. A new municipal solid waste landfill conforming to U.S. EPA and Guam EPA requirements is planned for a site in Dandan, Inarajan, and concrete steps towards the closing of Ordot dump and the construction of the new landfill were recently made with the signing of Executive Order 2007-2009, which outlines actions towards achieving compliance with the consent decree. In response to U.S. District Court orders, the Guam Waterworks Authority (GWA) is extending the sewage outfalls at the Northern (Tanguisson) and Hagatña STP sites into deeper water in order to meet NPDES requirements. The outfall extensions will be constructed using directional-drilling technology to bore under the fringing reefs with minor disturbance to the coral communities.

The Guam Seashore Reserve Plan Task Force, comprised of representatives from several of Guam's governmental agencies, developed a Guam Seashore Reserve Plan to better guide decisions of the Guam Seashore Protection Commission (GSPC). The GSPC has review and approval authority over construction projects proposed within the area from 10 m inland of the mean high tide mark out to a depth of 18.3 m (an area defined by law as the "seashore reserve"). The Plan will revise interim rules and regulations that have been in place since the passing of the Seashore Reserve Act in 1974 and provide clearer definitions and guidelines for managing development along the coast. The Seashore Reserve Plan also includes provisions for compensatory mitigation if a permitted project will have negative impacts on coastal resources.

### Fisheries Management Local Action Strategy

The fisheries management LAS, developed by DAWR and reviewed by fishermen, resource managers and other stakeholders, originally focused on increasing the effectiveness of Guam's marine preserves. The strategy addresses three main issues: lack of enforcement and prosecution, lack of public awareness and support and the need to assess the ability of the preserves to increase reef fish stocks. The fisheries management LAS has been one of the more successful LAS for Guam, as most of the tasks outlined in the original plan were completed. Through CRI funding, four vehicles and other equipment were purchased to facilitate better enforcement; DAWR has also obtained funding from NOAA to purchase a pair of jet skis in 2008, and efforts are underway to procure a patrol vessel to improve marine preserve enforcement. As part of this effort, DAWR has produced a user- friendly fisheries regulations booklet, printed updated marine preserve brochures and is currently working on a multimedia educational campaign for the marine preserves. In addition, monitoring programs are underway in three preserves, and DAWR has developed regulations to implement Public Laws 27-87 and 27-30, which establish a permitting system for non-fishing activities in Marine Preserves and create the Conservation Officer Reserve Program. With the addition of a dedicated natural resource attorney hired by DAWR, the Division hopes to improve prosecution of marine preserve violations and gain legal approval for DAWR's citation system and eco-permit system. The GCRICC has continued to convey the importance of Marine Preserves to all parts of the community, from elementary schools to the territorial legislature, and undertake research focusing on the assessment of fish biomass increases within the preserves and associated spillover effects.

*Current Management Activities*
**Fisheries Management**

- Strengthening of statutory laws
- Creation of Conservation Officer Reserve Program
- Development of eco-permitting program
- Purchase of four vehicles, two jet skis and equipment for enforcement
- Production of user-friendly fisheries regulation booklet
- Development of multi-media campaign for marine preserves
- Hiring of natural resources prosecutor
- Development of new goals for LAS

Several legislative advancements were designed to bolster the original three-year local action strategy for coral reef fishery management. The statutory laws regulating Guam's reef resources were strengthened in 2006 through Public Law 28-107. This law updated and expanded the definition of terms used within the regulations, closing a number of loopholes in the regulations for the marine preserves by defining the Chamoru terms for certain fish life stages such as I'e (juvenile jacks) and tiao (juvenile goatfish). It also strengthened the marine preserves by inserting two new sections into the 5 GCA, Chapter 63, defining the purpose of the Marine Preserves and the activities allowed in the marine preserves. Public Law 28-107 also expanded the definition of coral to include, "any live or dead member or part thereof of the Phylum Cnidaria that form calcareous skeletons, spicules or sclerites (including soft and hard corals both hermatypic and ahermatypic) or exist as sessile, solitary, or colonial polyps." In 2005, the legislature passed Public Law 28-30, which created a Conservation Officer Reserve Program designed to expand enforcement coverage by the addition of ten part-time civilian officers. Through CRI funding, DAWR has created the regulations governing this program, developed training modules, and procured equipment for the reserve officers. The program is scheduled to begin in early 2008, pending final approval.

As most of the original goals were met by 2005, DAWR developed a new set of goals for the fisheries management LAS. The new goals include identifying non-sustainable fishing practices, developing sustainable alternatives and developing

### Guam's Marine Preserves: Preserving our Marine Resources for the Future

> *"The purpose of the marine preserve is to protect, preserve, manage, and conserve aquatic life, habitat, and marine communities and ecosystems, and to ensure the health, welfare and integrity of marine resources for current and future generations."* – 5 GCA, Title 16, Chapter 63, §63116.1

In 1997, the government of Guam passed Guam Public Law 24-21, establishing five marine preserves around the island to restore Guam's fishery resources. In 2006, Public Law 28-107 expanded the purpose of the preserves to include the protection and preservation of aquatic life, habitat, and marine communities and ecosystems and strengthened the protection of the preserves by making all forms of fishing and the taking or altering of aquatic life, coral, and any other resources within a preserve unlawful unless specifically permitted by DAWR through regulations.

The preserves vary in size from 3-20 km$^2$ and protect a variety of habitats from 10 m above mean high tide to the 183 m (600 ft) depth contour, including an ecologically valuable mangrove area in Sasa Bay. The preserves are managed and enforced by the Guam DAWR.

| Preserve | Area (km$^2$) |
|---|---|
| Achang Reef Flat | 4.85 |
| Sasa Bay | 3.12 |
| Piti Bomb Holes | 3.63 |
| Tumon Bay | 4.52 |
| Pati Point | 20.00 |
| **Total:** | **36.12** |

Enforcement of the preserve regulations began in 2001. Current regulations allow limited take using specific methods or limited species, such as trolling for pelagic fish, shoreline hook and line fishing in the Pati Point Preserve for unrestricted species, and limited traditional take in the Tumon Bay Preserve for four species using specific hook and line or cast net methods. The department also issues special permits in the Achang Reef Flat and Piti Bomb Holes Preserves for traditional harvest of seasonal runs of juvenile rabbitfish (mañahak), juvenile jacks (I'e) and scads (atulai).

The Tumon Bay and Piti Bomb Holes Preserves are popular recreational sites, but the high level of use appears to have a detrimental effect on the marine ecosystems. DAWR is currently developing "eco-permitting" regulations that will allow the agency to place limitations on certain activities within the preserves and require a permitting process for all commercial uses of the preserve. DAWR hopes to involve the community in developing these limits.

Studies by DAWR and UOGML have indicated a substantial increase in the abundance of fish found within the preserves (Gutierrez, 2003; Tupper, in prep; Pioppi, in prep) and initial results of a study on larval transport and spillover suggest that the beneficial effects are extending outside of the preserve boundaries (M. Tupper, pers. comm.). Unfortunately, these improvements are hampered by illegal fishing within the preserves. To address this problem, DAWR has purchased equipment necessary for enforcement and developed a Conservation Officer Reserve Program to increase the number of officers patrolling the marine preserves as well as to educate the public about Guam's fisheries regulations. They have also launched a new educational campaign entitled "Marine Preserves are good for Guam. Marine Preserves are good for You," to help residents understand the benefits of marine preserves.

demand schedules to reduce overharvest. The specific objectives for this new LAS effort include: research on the structure of reef fish communities around the island; increased water quality monitoring in coastal areas; identification of fishing methods that have a disproportional effect on reef fish and an examination of alternatives that could ease the impact on reefs; provision of educational materials about reef fish biology and ecology to facilitate better harvest choices; and the identification of spawning periods and aggregation sites for key species.

## Lack of Public Awareness Local Action Strategy

The lack of public awareness LAS has been one of the more active and successful of Guam's LAS strategies. The coordination of multiple partners and the implementation of innovative social marketing techniques have increased the effectiveness of outreach efforts on Guam. The development of an engaged, active outreach coordinating body and a comprehensive coral reef outreach strategy, improved capacity, and the movement towards regularly conducted public awareness surveys all contributed to improved coral reef outreach and education activities. A promising sign is the significant increase in community participation in cleanups, tree plantings, recycling drives, and other events. The government of Guam has sought to further encourage environmental participation and leadership by establishing annual awards, such as the Environmental Steward of the Year and the Governor's Green School Award.

*Current Management Activities*
**Lack of Public Awareness**

- Island Pride events
- Development of school curriculum
- Marketing survey to evaluate effectiveness of outreach efforts
- Guardian's of the Reef program
- International coastal cleanup
- Marine Debris campaign
- International Year of the Reef activities planned for 2008

The Guam Environmental Education Committee (GEEC), comprised of representatives from a wide array of government agencies, private businesses and community groups, has made significant strides towards a comprehensive environmental education and outreach program that involves many partners and utilizes multiple products and media outlets. The GEEC developed an environmental education strategy to provide guidance to government agencies regarding environmental outreach efforts. The work of the GEEC has been coordinated with and supplemented by the Guam Environmental Education Partners, Inc. (GEEPI), which serves as a non-governmental partner in outreach and education efforts.

Numerous island pride events have also been carried out since 2004. The Island Pride Program, which was developed by GCRICC members, combines educational and environmental activities with fun events designed to instill a sense of stewardship among the island's youth. Island Pride events conducted since 2004 include annual Island Pride/Earth Day festivals, beach cleanups, an annual kid's fishing derby at the WAPA, tree planting, and recycling drives at parades and other events. Public participation in these events has grown considerably in recent years. The campaign has also strengthened ties among the GCRICC and GVB, as well as with the private sector which has helped sponsor these events. A series of environmental education and outreach products was developed to promote coral reef awareness as part of the campaign. The campaign prominently features Professor Kika Clearwater, a cartoon spokesperson, on a variety of products (Figure 15.32). Products include a video played on the Visitor's Channel, posters, hotel tent cards, a quarterly newsletter, calendars, movie theater intermission slides, a recycling guide, marine life identification slates, and public service announcements for radio, newspaper and television. Teacher guides and school curricula are also under development.

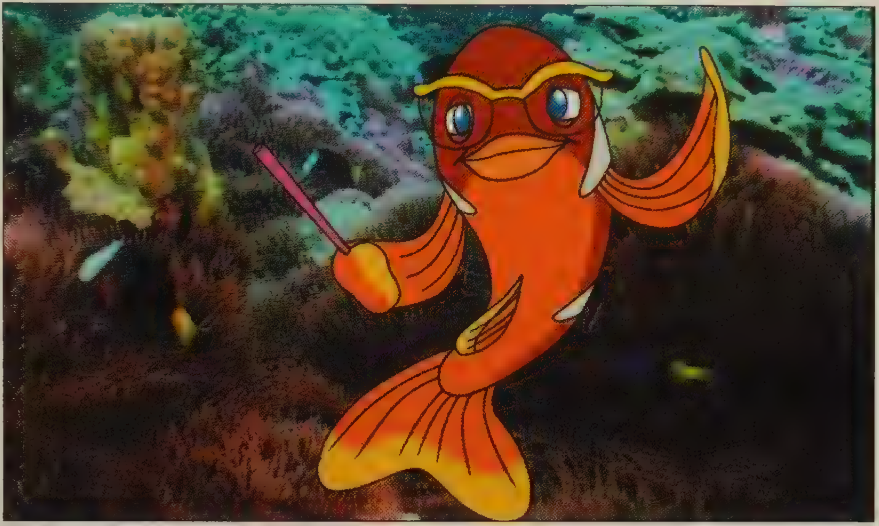


*Figure 15.32. Professor Kika Clearwater, mascot of the Island Pride Campaign, is featured in a variety of products for visitors and residents to raise awareness of coral reef issues.*

The Guardians of the Reef project, developed by the NOAA Coral Fellow for Guam and the GCMP, utilizes local 11th and 12th grade students to provide coral reef-focused educational opportunities to 3rd grade students. In 2007, 20 pairs of high school students each developed a one-hour program, which was presented to about half of the 3rd grade classrooms in public schools around the island. The success of the Guardians of the Reef project has encouraged other high schools to participate; the program may be expanded to all public and private schools on Guam in 2008.

Several other campaigns planned for 2008 by partner organizations will further increase public awareness of coral reef issues. The GCMP, GEEPI and NOAA PIRO will be spearheading a year-long campaign to coincide with the International Year of the Reef in 2008 (IYOR08). The signing of an Executive Order declaring 2008 as International Year of the Reef will kick off the campaign, followed by dozens of activities planned throughout the year. The first Guam Coral Reef Symposium, which will feature presentations from managers, researchers, educators, and others working on CRI-funded projects, will also be introduced with the IYOR08 campaign. NOAA's PIRO obtained funding from the NOAA Marine Debris Program for a marine debris education campaign for Guam designed to increase residents' awareness of marine debris impacts and promote stewardship for coastal and marine resources. This program will be supplemented by a community-based marine debris education and prevention campaign designed by Micronesian Divers Association, a local dive shop, in coordination with the Guam Marine Awareness Foundation and funded by the NOAA Marine Debris Program Community-based Marine Debris Prevention and Removal Grants.

### Recreational Misuse and Overuse

While the impacts of recreational misuse and overuse are not as pervasive as threats such as sedimentation, stormwater runoff and overfishing, the impacts of recreational users can cause localized degradation to high value reef habitat. Several steps have been made to address the threat of recreational misuse and overuse under the Recreational Misuse and Overuse LAS.

With the passing of Public Law 27-87 in May 2004, which creates a marine preserve eco-permitting system administered by DAWR to address non-fishing activities in Guam's Marine Preserves, DAWR developed a fee schedule and a permitting plan for carrying out its new regulatory authority. The rules and regulations are awaiting legal review before they can be approved. A workshop was conducted in May 2005 to receive input from stakeholders regarding the eco-permitting plan. The workshop also provided information to commercial operators and recreational users regarding the impact of recreational users on Guam's coral reefs.

A study of the effects of personal watercraft use on marine communities in East Agana Bay was completed in 2006 (PCR Environmental, Inc., 2006). The results of the study, which indicate little or no observable impact on the marine communities in the study areas, will be used to help update the Recreational Water Use Master Plan. A study to identify alternative sites for beginning SCUBA divers will be carried out in 2008. This study, which will also examine possible modifications of existing sites, should provide resource mangers with options for reducing the high level of recreational use, and the associated impacts on the ecosystem, in the Piti Bomb Holes and TBMP.

Natural resource management agencies have continued to engage stakeholders within the tourism sector, including the GVB and the Guam Hotel and Restaurant Association, in marketing Guam's coral reefs and marine preserves to the one million visitors that arrive annually. An ongoing campaign launched by GVB, in association with GCMP, involves a range of projects aimed at educating tourists about the value of Tumon Bay's marine community and ways to reduce their physical impacts. The campaign is comprised of a range of activities, such as the installation of four education kiosks along Tumon Bay, the development and distribution of waterproof marine life identification slates, the development and local use of school curricula and teacher guides, and screening of an educational video on the Visitor's Channel to educate tourists about how to avoid damaging coral reefs.

*Current Management Activities*
**Recreational Misuse/Overuse**

- Development of eco-permitting plan to regulate non-fishing activities in marine preserves
- Recreational Impacts workshop
- Informational kiosks along Tumon Bay
- In-flight video for tourists arriving from Japan
- Study to identify alternate introductory scuba sites
- Study evaluating impacts of PWC on marine communities in East Agana Bay
- Update of Recreational Water Use Master Plan

### Coral Bleaching and Disease

The Coral Bleaching and Disease LAS continues to be one of the most challenging to address at a local scale. Previous activities under this LAS primarily involved management efforts covered by other LAS to reduce local anthropogenic stressors, raise public awareness, and improve coordination among resource agencies with regard to reef resiliency and climate change. Recent activities under the coral bleaching and disease LAS have more directly addressed the threats of coral bleaching and disease by improving our understanding of how coral diseases and bleaching affect Guam's reefs, increasing the ability of the natural resource agencies and UOGML to respond to bleaching and disease events, and improving protected area design and management through the incorporation of resiliency to climate change.

*Current Management Activities*
**Coral Bleaching and Disease**

- Baseline assessment of coral disease prevalence
- Long-term monitoring of coral disease
- Coral disease workshop
- Development of bleaching response plan

As described in the Benthic Habitats section, a baseline coral disease assessment was carried out in 2006 and 2007, and a long-term program for monitoring coral diseases was initiated. In addition, a coral disease workshop was conducted at the UOGML to improve local capacity in responding to disease events. Several representatives from Guam also attended a workshop conducted by NOAA and the Great Barrier Reef Marine Park Authority entitled, *Responding to Climate Change: a Workshop for Coral Reef Managers* in August 2007. The workshop was geared toward managers and biologists from various Pacific jurisdictions and provided information about the threat of coral bleaching and training in the use of NOAA's satellite monitoring tools. The workshop also prompted the development of a coral bleaching response plan for Guam as part of a larger coral reef response plan, which will provide protocols for predicting and monitoring bleaching events as well as guidance for incorporating reef resiliency into coral reef management efforts.

### Military Expansion on Guam

The GCRICC has identified as a priority the potential threat of the planned military expansion on Guam's coral reef ecosystem and is currently developing a LAS to address it. Projects under this LAS may include: independent assessments of the environmental impacts of certain military activities; legal assistance in the development of a compensatory mitigation policy; a review of current legislation; an update of the building code to include the U.S. Green-Building Council's Leadership in Energy and Environmental Design recommendations; the development of a model for determining the cumulative and secondary impacts of various land use activities on the northern aquifer; public outreach efforts; and invasive species-related projects.

### Guam Coral Reef Monitoring and Response Plans

Guam has made great strides since 2004 in addressing gaps in monitoring efforts. The multi-agency Guam Coral Reef Monitoring Group (GCRMG) developed an island-wide monitoring strategy that incorporates existing monitoring programs, including Guam EPA's EMAP and Status and Trends Monitoring programs, DAWR's Marine Preserve Monitoring, UOGML's long-term monitoring program and NPS monitoring activities. The territorial monitoring program, which will also include the establishment of additional long-term monitoring sites, will provide data for a number of parameters useful in assessing coral reef ecosystem health and identifying specific stressors. The monitoring program will allow resource managers to evaluate the effectiveness of specific management strategies and serve as an early warning system for changes in reef health. The implementation of a three-year block grant, as recommended in the 2005 report, provided an important foundation for the long-term monitoring strategy, and facilitated the significant expansion of monitoring sites, the procurement of a central monitoring data server, and the development of a web-based data entry and automated report-generation application.

Guam is also developing a coral reef response plan for coral bleaching, disease, COTS outbreaks, groundings, spills and storm damage. The plan will establish protocols for responding to a number of disturbance events including the assessment of vessel grounding and spill impacts to determine compensatory mitigation, rapid response for coral disease outbreaks (e.g., identifying the disease(s), assessing prevalence and coral mortality and collecting tissue samples), assessment and control of COTS outbreaks, and post-storm coral community assessments and cleanup efforts. The response plan will also outline the development of community watch programs for COTS, bleaching and disease.

## New Approaches to Coral Reef Management

### *Conservation Action Planning*

In preparation for the next iteration of Guam's local action strategies, members of the GCRICC explored the use of a process developed by TNC called Conservation Action Planning (CAP) to develop a site-based local action strategy for the Piti Bomb Holes Marine Preserve and adjacent watershed. As part of the process, the GCRICC developed a preliminary list of focal conservation targets with an assessment of their viability, and identified and ranked critical threats affecting the focal targets. The group also developed a preliminary list of strategic objectives and actions to either abate the critical threats or enhance the viability of the targets, and practical indicators to measure success. Finally, the group conducted a self-assessment of their capacity to implement this conservation action plan.

The group identified certain benefits of using a site-based approach in developing their next round of LAS, including compatibility with Guam's watershed planning process, the ability to more objectively prioritize targets, threats, actions, and resources, as well as the strengthening of the GCRICC by bringing together members with diverse technical expertise to holistically address multiple threats at one site, allowing for the prioritization of sites versus projects. In early 2007, the GCRICC began coordinating with the Piti Mayor's office to engage the community in the process of implementing actions identified in the Piti LAS/CAP. A consultant from the Center for Watershed Protection will assist in the development of watershed management plan for the Piti-Asan watershed. Funding has been secured for large-scale revegetation efforts in the watershed beginning in 2008.

### *The Micronesia Challenge*

In January 2006, Governor Felix P. Camacho signed the Micronesia Challenge (MC), a commitment by the Chief Executives of Guam, the Commonwealth of the Northern Mariana Islands, the Federated States of Micronesia, the Republic of the Marshall Islands and the Republic of Palau to effectively conserve at least 30% of nearshore marine resources and 20% of terrestrial resources across Micronesia by 2020 (see the National Level Activities chapter for more information about the MC). Along with the other jurisdictions, Guam has a strategy to implement the MC, involving partnerships between government agencies, NGOs and local communities. One of the first actions Guam is undertaking is the development of a sustainable financing plan to be completed in early 2008. The plan will identify the level and sources of funding needed to effectively manage Guam's natural resources and meet the goals of the MC.

## OVERALL CONCLUSIONS AND RECOMMENDATIONS

Similar to what was reported in 2005, the health of Guam's coral reefs varies significantly across the island. In general, reefs in the northern part of the island and southern reefs at sufficient distances from rivers are relatively healthy, while large sections of reef in the south, particularly those near river mouths, are in poor to fair condition. Chronic COTS outbreaks have affected numerous reefs around the island in the last few years, including some reefs previously characterized by relatively high coral cover and diversity. Individual fish >25 cm are uncommon to rare on Guam, and while their numbers are slightly higher on northern reefs, medium and large fish abundance is still very low compared to other islands in the Mariana Archipelago. The ability of some reefs on Guam to recover from their current degraded state and from acute disturbance events such as COTS outbreaks, storms and bleaching events, is likely hindered by poor water quality, low target herbivorous fish abundance and low coral recruitment.

The GCRICC and a broad network of local and federal agencies, NGOs, legislators, private enterprises, teachers, students and other concerned citizens continue to partner in the implementation of ambitious and creative ways to address the primary threats to Guam's coral reefs. Re-vegetation efforts, outreach campaigns, enforcement within marine preserves, development of a comprehensive monitoring strategy, the strengthening of existing policies and the planned implementation of new ones are all examples of Guam's commitment to improving the health of its coral reef resources. Major public works projects, including the extension of sewage outfalls and the closing of Ordot dump, will also contribute to a healthier reef system. Guam's participation in the MC represents a major step towards effective management of the island's natural resources, setting achievable conservation goals and providing an opportunity to further engage the community in natural resource management. The increasing level of community participation in cleanups and erosion control efforts, as well as the success of outreach and education activities like the Island Pride Campaign and the Guardians of the Reef Program, indicates that public awareness is increasing.

Although Guam has made a great deal of progress in coral reef protection, monitoring and public outreach over the past several years, many challenges still remain. Financial and human resources remain limited compared to the need, and are disproportionate to the value of goods and services generated by coral reefs. Present capacity will be further stretched by the planned military expansion and by the additional responsibilities required to carry out new programs. The military expansion presents a direct threat to coral reef resources through dredging and filling of reef areas, as well as an indirect threat stemming from the consumption, recreational and housing demands that the tens of thousands of new residents will place on Guam's reef resources. Wildland arson is still a major problem in many watersheds in southern Guam, and stormwater runoff and aquifer discharge continue to contribute excessive volumes of freshwater, nutrients, heavy metals and other pollutants to nearshore waters, impacting high-value reef systems such as Tumon Bay.

Global climate change poses a particularly grave and increasingly pressing threat to the vitality of Guam's reefs. The expected increase in incidences of coral bleaching, ocean acidification and the potential for stronger storms will directly affect reef health, challenging even the most resilient reefs. Expected economic and social changes at the global, regional, and national levels are likely to strain resources devoted to coral reef management as priorities shift to cope with the impacts of migration, poverty and disease associated with climate instability (Stern, 2006).

Policy interventions must be prioritized in an economically sound manner in order to most efficiently allocate the limited financial and human resources available to coral reef managers to address pressing issues of coral reef degradation in a timely manner. The use of extended cost-benefit analyses would help identify management actions that provide the most benefit for the lowest cost. Site-based approaches, facilitated by the CAP or similar tools and involving strong community participation and a coordinated network of multiple organizations, would focus resources on management actions that address a spectrum of threats within a specific area. In order to more effectively address current threats to Guam's coral reefs and to prepare for threats associated with the planned military expansion, local and federal agencies must actively push to ensure that important plans and programs, including the Eco-Permitting Program, the Seashore Reserve Plan and the Conservation Officer Reserve Program are implemented immediately. The financial and staff capacity of the resource management community must be significantly increased if current coral reef threats and threats associated with the anticipated military expansion are to be adequately addressed.

It is crucial to expand and expedite re-vegetation efforts and eliminate the threat of wildland fires in order to restore watershed integrity and nearshore water quality, allowing the recovery of once-productive reef systems and enhancing their capacity for long-term survival. Stop-gap measures to prevent soil erosion should be implemented broadly as soon as possible, followed by restoration of native vegetation. Additional funding and active community involvement will be needed to achieve success on an island-wide scale. The disproportionate contribution of a small number of poachers to large-scale watershed degradation must be addressed through aggressive and creative enforcement, application of steep penalties that are proportionate to the damage that results and intense outreach to communities affected by the fires.

Future environmental outreach and education efforts should continue to build on the success of efforts such as the Island Pride Campaign and the Guardians of the Reef Program, encouraging even greater participation in these events and further engaging the public through community-based monitoring and management efforts. The effectiveness of outreach and education activities can be improved by further implementing social marketing techniques and by utilizing information obtained through regularly-conducted socioeconomic surveys. There is a great need in Guam for more community-driven action; the natural resource management agencies and partnering organizations and institutions can help facilitate this through internships, training, and other opportunities for future environmental leaders and enable the development of community-based, environmentally-focused NGOs, which are lacking on Guam.

Although fish abundance has increased within the marine preserves and spillover is becoming apparent, additional fisheries management tools are necessary to address the severe depletion of key reef fisheries on Guam. Species-specific regulations, such as size limits or closures during spawning seasons, and limits on exploitative fishing practices are required to restore populations of large, slow-growing species that aren't effectively protected by the preserves. Particular attention should be placed on protecting large herbivorous fish and iconic species such as napoleon wrasse, possibly including a ban on the take of these species. The results of surveys conducted for the economic valuation study indicate that there is support among the public for a ban on scuba spearfishing and the use of monofilament gill-nets. The involvement of the community, and fishermen in particular, will be crucial in addressing these concerns. Following the lead of American Samoa, the Commonwealth of the Northern Mariana Islands, and numerous other nations around the world, Guam should consider banning particularly exploitative, non-traditional fishing methods immediately to help to restore vulnerable reef fish populations, preserve cultural fishing practices and improve overall coral reef ecosystem health.

Natural resource management agencies must actively involve the tourism industry and the community in the development of sustainable coral reef management policies to address the impacts of tourism on Guam's reefs. Recreational misuse and overuse at highly valued sites, such as Tumon and Piti Bays, requires immediate attention. The Eco-permitting Program, once approved, will provide the mechanism through which non-fishing activities can be limited within the preserves, but more information is required to achieve sustainable levels of recreational use without further damaging the resource or jeopardizing the viability of responsible commercial operators.

It is clear that the ability of Guam's reefs to cope with climate change must be enhanced significantly if productive reef systems, and the goods and services they provide, are to be available to future generations. To achieve this will require a deep commitment to the rapid, large-scale reduction in the threats currently affecting Guam's reefs. It will also require a vastly improved understanding of reef resilience to climate change and the effective integration of the concept of resiliency into a viable, long-term coral reef management strategy.

## REFERENCES

Agency for Toxic Substances and Disease Registry. 2002. ATSDR preliminary public health findings on fish sampling: Orote landfill site, Guam. http://www.atsdr.cdc.gov/NEWS/orotefs_032002.html.

Amesbury, S., V. Bonito, R. Chang, L. Kirkendale, C. Meyer, G. Paulay, R. Ritson-Williams, and T. Rongo. 2001. Marine biodiversity resource survey and baseline reef monitoring survey of the Haputo Ecological Reserve Area, COMNAVMARIANAS. Report and Interactive GIS Document prepared for U.S. Department of Defense, COMNAVMARIANAS. 111 pp.

Amesbury, J.R. and R.L. Hunter-Anderson. 2003. Review of archaeological and historical data concerning reef fishing in the U.S. flag islands of Micronesia: Guam and the Northern Mariana Islands. Final Report. Western Pacific Regional Fishery Management Council. 147 pp.

Best, B.R. and C.E. Davidson. 1981. Inventory and atlas of the inland aquatic ecosystems of the Marianas Archipelago. Technical Report 75. The Marine Laboratory, University of Guam. Mangilao, Guam. 226 pp.

Birkeland, C. 1997. Status of coral reefs in the Marianas. pp. 91-100. In: R.W. Grigg and C. Birkeland. (eds.) Status of coral reefs in the Pacific. UNIHI-SEAGRANT-CP-98-01. University of Hawaii Sea Grant Program. Honolulu, HI. 144 pp.

Birkeland, C., D. Rowley, and R.H. Randall. 1981. Coral recruitment patterns at Guam. pp. 2: 339-344. In: E.D. Gomez, C.E. Birkeland, R.W. Buddemeier, R.E. Johannes, J.A. March Jr., and R.T. Tsuda (eds.). Proceedings of the 4th International Coral Reef Symposium, Vol. 2. Manila, Philippines. 780 pp.

Borja, J. Agricultural Development Services, Guam Department of Agriculture. Mangilao, Guam. Personal communication.

Brown, V.A. 2007. Guam Coral Bleaching Event September - October 2006. NMFS/PIRO/HCD Incident Report. December 2006.

Bruno, J.F. and E. Selig. 2007. Regional decline of coral cover in the Indo-Pacific: Timing, extent, and subregional comparisons. PLos ONE 8: 1-8.

Burdick, D. 2006. Guam Coastal Atlas. Technical Report 114. The Marine Laboratory, University of Guam. Mangilao, Guam. 149 pp.

Cheney, D.P. 1977. Hard tissue tumors of scleractinian corals. Adv. Exp. Med. Biol. 64:77-87.

Colgan, M. 1987. Coral reef recovery on Guam (Micronesia) after catastrophic predation by *Acanthaster planci*. Ecology 68(6): 1592-1605.

Collins, J.M. 1995. Occurrence and fate of fecal pollution indicator bacteria in sediments of Tumon Bay, Guam. M.S. Thesis. The Marine Laboratory, University of Guam. Mangilao, Guam. 75 pp.

Commander Navy Region Marianas. 2005. Update on Orote Landfill groundwater investigation. Fact sheet No. 4. http://www.guam.navy.mil/Restoration%20Board/Orote%20Fact%20Sheet%20Aug%2005%20rev%2005.pdf.

Commander Navy Region Marianas. 2007. Kilo Wharf Extension (MILCON P-502), Apra Harbor Naval Complex, Guam, Marianas Islands. Final Environmental Impact Statement. Department of the Navy, U.S. Department of Defence and U.S. Environmental Protection Agency. 332 pp.

CRC Reef Research Centre. 2003. Crown-of-thorns starfish on the Great Barrier Reef: Current state of knowledge. 6pp. http://www.reef.crc.org.au/publications/brochures/COTS_web_Nov2003.pdf.

DeMeo, R.A., Z.R. Sims, R.W. Wescom, and R. White. 1995. Draft Resource Assessment, Ugum Watershed, Guam. 92 pp.

Denton, G.R.W., H.R. Wood, L.P. Concepcion, H.G. Siegrist, Jr., V.S. Eflin, D.K. Narcis, and G. T. Pangelinan. 1997. Analysis of in-place contamination in marine sediments from four harbor locations on Guam. Water and Environmental Research Institute of the Western Pacific, University of Guam. Technical Report 81. 120 pp.

Denton, G.R.W., H.R. Wood, L.P. Concepcion, V.S. Eflin, and G.T. Pangelinan. 1999. Heavy metals, PCBs and PAHs in marine organisms from four harbor locations on Guam. Technical Report 87. Water and Environmental Research Institute of the Western Pacific, University of Guam. Mangilao, Guam. 158 pp. http://www.weriguam.org/reports/index.php.

Denton, G.R.W., M.H. Golabi, C. Iyekar, H.R. Wood, and Y. Wen. 2005a. Mobilization of aqueous contaminants leached from Ordot Landfill in surface and subsurface flows. Technical Report 108. Water and Environmental Research Institute of the Western Pacific, University of Guam. Mangilao, Guam. 83 pp. http://www.weriguam.org/reports/index.php.

Denton, G.R.W., C.M. Sian-Denton, L.C. Concepcion, and H.R. Wood. 2005b. Nutrient status of Tumon Bay in relation to intertidal blooms of the filamentous green algae Enteromorpha clathrata. Technical Report 110. Water and Environmental Research Institute of the Western Pacific, University of Guam. Mangilao, Guam. 53 pp. http://www.weriguam.org/reports/index.php.

Denton, G.R.W., W.C. Kelly, H.R. Wood, and Y. Wen. 2006. Impact of metal enriched leachate from Ordot Dump on the heavy metal status of biotic and abiotic components in Pago Bay. Technical Report 113. Water and Environmental Research Institute of the Western Pacific, University of Guam. Mangilao, Guam. 63 pp. http://www.weriguam.org/reports/index.php

Element Environmental, LLC. 2006. Environmental Site Investigation, Former LORAN Station Cocos Island, Cocos Island, Guam. Draft Report for U.S. Coast Guard.

Emanuel, K. 2005. Increasing destructiveness of tropical cyclones over the past 30 years. Nature 436(4): 686-688.

English, S., C. Wilkinson, and V. Baker. 1997. Survey manual for tropical marine resources. 2nd Ed. Australian Institute of Marine Science. Townsville, Australia. 402 pp.

Flores, T. Division of Aquatic and Wildlife Resources, Guam Department of Agriculture. Mangilao, Guam. Personal communication.

Flores, T. 2006a. Offshore Fisheries Program Annual Program Report FY 2006. Annual Report. Division of Aquatic and Wildlife Resources, Department of Agriculture, Government of Guam. Mangilao, Guam. 8 pp.

Flores, T. 2006b. Inshore Fisheries Participation, Effort, and Harvest Surveys Program. Annual Program Report FY 2006. Division of Aquatic and Wildlife Resources, Guam Department of Agriculture. Mangilao, Guam. 5 pp.

Gilmour, J. 1999. Experimental investigation into the effects of suspended sediment on fertilization, larval survival and settlement in a scleractinian coral. Mar. Biol. 135: 451-462.

Guam Civilian Military Task Force. 2007. Planning for military growth: A preliminary needs assessment. 190 pp.

Guam Environmental Protection Agency. 2001. Revised Guam Water Quality Standards. Public Law 26-32. 122 pp.

Guam Visitors Bureau. 2006. Guam Visitors Bureau Five Year Strategic Plan: 2007-2011. http://www.visitguam.org/activities/?pg=5_year_strategic_plan.

Gutierrez, J.T. 2003. Fisheries participation, effort, and harvest surveys. Division of Aquatic and Wildlife Resources, Guam Department of Agriculture. Mangilao, Guam. 24 pp.

Hawkins, J.P. and C.M. Roberts. 1997. Estimating the carrying capacity of coral reefs for scuba diving. pp. 1923-1926. In: H.A. Lessios and I.G. Macintyre (eds.). Proceedings of the 8th International Coral Reef Symposium, Vol. 2. Panama City, Panama. 2118 pp.

Hawkins, J.P., C.M. Roberts, T.V.H. Kalli De Meyer, J. Tratalos, and C. Aldam. 1999. Effects of recreational scuba diving on Caribbean coral and fish communities. Conserv. Biol. 13(4): 888-897.

Helber, Hastert & Fee, Planners. 2006. Guam Integrated Military Development Plan.

Helton, G., I. Zelo, C. Lord, and C. Plank. 2003. Surveys of abandoned vessels: Guam and the Commonwealth of the Northern Mariana Islands. 165 pp. http://response.restoration.noaa.gov/book_shelf/505_AVP_PacificReport.pdf.

Hodgson, G. 1990. Sediment and the settlement of larvae of the reef coral *Pocillopora damicornis*. Coral Reefs. 9(1): 41-3.

Hoegh-Guldberg, O. 1999. Coral bleaching, climate change and the future of the world's coral reefs. Mar. Freshw. Res. 50(8): 839-866.

Hunter, C.L. 1995. Review of coral reefs around American flag Pacific islands and assessment of need, value, and feasibility of establishing a coral reef fishery management plan for the western Pacific region. Final Report. Western Pacific Regional Fishery Management Council. Honolulu, HI. 30 pp.

Hutchings, P.A., R.W. Hilliard, and S.L. Coles. 2002. Species introductions and potential for marine pest invasions into tropical marine communities, with special reference to the Indo-Pacific. Pac. Sci. 56(2): 223-233.

Jokiel, P.L., C.L. Hunter, S. Taguchi, and L. Watarai. 1993. Ecological impact of a fresh-water "reef kill" in Kaneohe Bay, Oahu, Hawaii. Coral Reefs 12: 177-184.

Kleypas, J.A., R.W. Buddemeier, D.A. Archer, J.P. Gattuso, C. Langdon, and B.N. Opdyke. 1999. Geochemical consequences of increased atmospheric carbon dioxide on coral reefs. Science 284: 118-120.

Lander, M.A. 2004. Rainfall climatology for Saipan: Distribution, return-periods, El Niño, tropical cyclones, and long-term variations. Technical Report 103. Water and Environmental Research Institute of the Western Pacific, University of Guam. Mangilao, Guam. 54 pp. http://www.weriguam.org/reports/index.php.

Lander, M.A. and C.P. Guard. 2003. Creation of a 50-year rainfall database, annual rainfall climatology, and annual rainfall distribution map for Guam. Technical Report 102. Water and Environmental Research Institute of the Western Pacific, University of Guam. Mangilao, Guam. 20 pp. http://www.weriguam.org/reports/index.php.

Lundgren, I. and D. Minton. 2005. Is coral recruitment limited by sedimentation at War in the Pacific National Historical Park? pp. 375-384. In: D. Harmon (ed.). People, Places, and Parks: Proceedings of the 2005 George Wright Society Conference on Parks, Protected Areas, and Cultural Sites. The George Wright Society. Hancock, MI. 488 pp. http://www.georgewright.org/2005proc.html.

Meehl, G.A., T.F. Stocker, W.D. Collins, P. Friedlingstein, A.T. Gaye, J.M. Gregory, A. Kitoh, R. Knutti, J.M. Murphy, A. Noda, S.C.B. Raper, I.G. Watterson, A.J. Weaver, and Z.C. Zhao. 2007. Global Climate Projections. pp. 747-845. In: S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor, and H.L. Miller (eds.). Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK and New York, NY. 1009 pp.

Minton, D. 2005. Fire, erosion, and sedimentation in the Asan-Piti watershed and War in the Pacific NHP, Guam. Report prepared for the National Park Service. PCSU Technical Report 150. Pacific Cooperative Studies Unit (PCSU), Department of Botany, University of Hawaii at Manoa. Honolulu, HI. 99 pp. http://www.nps.gov/wapa/parkmgmt/index.htm.

Minton, D., I. Lundgren, A. Pakenham, D. Drake, and H. Tupper. 2005. Spatial and temporal patterns in sediment collection rates on coral reefs at War in the Pacific National Historic Park, Territory of Guam. pp. 385-390. In: D. Harmon (ed.). People, Places, and Parks: Proceedings of the 2005 George Wright Society Conference on Parks, Protected Areas, and Cultural Sites. The George Wright Society. Hancock, MI. 488 pp. http://www.georgewright.org/2005proc.html.

Minton, D. and I. Lundgren. 2006. Coral recruitment and sedimentation in Asan Bay and War in the Pacific NHP, Guam. Report prepared for the National Park Service. 29 pp. http://www.nps.gov/wapa/parkmgmt/index.htm.

Minton, D. and A. Palmer. 2006. Historical record of tropical cyclones on Saipan, Commonwealth of the Northern Marianas Islands (1945-2005). 2006. Technical report prepared for the National Park Service. 21 pp.

Minton, D., I. Lundgren, and A. Pakenham. In preparation. A two-year study of coral recruitment and sedimentation in Asan Bay, Guam. Report prepared for the National Park Service. 29 pp.

Moran, D.C. 2002. Qualitative groundwater dye trace of the Harmon Sink and Guam International Airport Authority. M.S. Thesis, University of Guam. Mangilao, Guam. 55 pp.

Neudecker, S. 1976. Development and environmental quality of coral reef communities near the Tanguisson power plant. Technical Report 30. The Marine Laboratory, University of Guam. Mangilao, Guam. 68 pp.

Neudecker, S. 1981. Effects of substratum orientation, depth, and time on coral recruitment at Guam. pp. 173-180. In: E.D. Gomez, C.E. Birkeland, R.W. Buddemeier, R.E. Johannes, J.A. March Jr., and R.T. Tsuda (eds.). Proceedings of the 4th International Coral Reef Symposium, Vol. 1. Manila, Philippines. 720 pp.

Paulay, G. 2003. Marine Biodiversity of Guam and the Marianas: overview. Micronesica 35-36: 3-25.

Paulay, G. and Y. Benayahu. 1999. Patterns and consequences of coral bleaching in Micronesia (Majuro and Guam) in 1992-1994. Micronesica 32(1): 109-124.

Paulay, G., L. Kirkendale, C. Meyer, P. Houk, T. Rongo, T. and R. Chang. 2001. Marine biodiversity resource survey and baseline reef monitoring survey of the Southern Orote Peninsula and North Agat Bay Area, COMNAVMARIANAS. Report and Interactive GIS Document prepared for U.S. Department of Defense, COMNAVMARIANAS. 111 pp.

PCR Environmental, Inc. 2002a. Sampling of Tumon Bay springs for chemical analysis. Guam Environmental Protection Agency. 125 pp.

PCR Environmental, Inc. 2002b. Sampling of Tumon Bay springs for chemical and bacterial analysis. Guam Environmental Protection Agency. 125 pp.

PCR Environmental, Inc. 2002c. Summary Report of Tumon Bay springs for chemical analysis. Guam Environmental Protection Agency. 125 pp.

PCR Environmental, Inc. 2006. Direct, cumulative, and secondary impacts of personal watercraft in East Agana Bay. Prepared for Guam Bureau of Statistics and Plans.

Pike, C. 2007. Guam Tourism Economic Impact: Preliminary Results. Prepared for Guam Visitors Bureau. Global Insight, Inc. 14 pp.

Pioppi, N. In preparation. M.S. Thesis. The Marine Laboratory, University of Guam. Mangilao, Guam.

Porter, V., T. Leberer, M. Gawel, J. Gutierrez, D. Burdick, V. Torres, and E. Lujan. The State of the Coral Reef Ecosystems Of Guam. pp. 442-487. In: J.E. Waddell (ed.). The State of the Coral Reef Ecosystems of the United States and Pacific Freely Associated States: 2005. NOAA Technical Memorandum NOS NCCOS 11. Silver Spring, MD. 522 pp.

Preskitt, L.B., P.S. Vroom, and C.M. Smith. 2004. A rapid ecological assessment (REA) quantitative survey method for benthic algae using photo quadrats with SCUBA. Pac. Sci. 58: 201-209.

QMark Research and Polling, Inc. 2005. Guam Coastal Management Program Study. Prepared for the Guam Coastal Management Program, Guam Bureau of Statistics and Plans. 15 pp.

Randall, R.H. 1971. Tanguisson-Tumon, Guam coral reefs before, during and after the crown-of-thorns starfish (*Acanthaster*) predation. M.S. Thesis, Department of Biology, University of Guam. Mangilao, Guam. 119 pp.

Randall, R.H., and L.G. Eldredge. 1976. Atlas of the reefs and beaches of Guam. Technical Report 19. The Marine Science Laboratory, University of Guam. Mangilao, Guam. 191 pp.

Raymundo, L.J., C. D. Harvell, and T. Reynolds. 2003. *Porites ulcerative* white spot disease: description, prevalence and host range of a new coral disease affecting Indo-Pacific Reefs. Dis. Aquat. Org. 56: 95-104.

Raymundo, L.J., K.B. Rosell, C. Reboton, and L. Kaczmarsky. 2005. Coral diseases on Philippine reefs: genus *Porites* is a dominant host. Dis. Aquat. Org. 64: 181-191.

Richmond, R.H. 1993. Coral reefs: present problems and future concerns resulting from anthropogenic disturbance. Am. Zool. 33: 524-536.

Richmond, R.H. 2000. Coral Reefs – How Do They Work and What Do They Provide. Division of Fish and Wildlife, Commonwealth of the Northern Mariana Islands Government. http://www.dfw.gov.mp/education/edsectfs.htm.

Richmond, R.H., T. Rongo, Y. Golbuu, S. Victor, N. Idechong, G. Davis, W. Kostka, L. Neth, M. Hamnett, and E. Wolanski. 2007. Watersheds and coral reefs: Conservation Science, Policy, and Implementation. Bioscience 57(7): 598-607.

Rohmann, S.O., J.J. Hayes, R. C. Newhall, M.E. Monaco, and R.W. Grigg. 2005. The area of potential shallow-water tropical and subtropical coral ecosystems in the Unites States. Coral Reefs 24: 370-383.

Russell, D.J. 1992. The ecological invasion of Hawaiian reefs by two marine red algae, *Acanthophora spicifera* (Vahl) Boerg. and *Hypnea musciformis* (Wulfen) J. Ag., and their association with two native species, *Laurencia nidifica* J. Ag. and *Hypnea cervicornis* J. Ag. ICES J. Mar Sci. 194: 110-125.

Schroeder, R.E., M.S. Trianni, K.A. Moots, J.L. Laughlin, B.J. Zgliczynski, and R.B. Tibbetts. 2006. Status of fishery target species on coral reefs of the Marianas Archipelago. pp.1016-1027. In: Proceedings of the 10th International Coral Reef Symposium. Okinawa, Japan. 1950 pp.

Stern, N. 2006. Stern Review on the Economics of Climate Change. Cabinet Office , HM Treasury, UK. 575 pp.

The Ocean Conservancy. 2007. 2006 International Coastal Cleanup: Summary report for Guam. 8pp. http://www.oceanconservancy.org/site/News2?page=NewsArticle&id=10393.

Tibbatts, B. 2006. Shallow bottom fish survey of the Southern Mariana Islands. Presentation to the Western Pacific Regional Fisheries Management Council.

Tomascik, T. 1991. Settlement patterns of Caribbean scleractinian corals on artificial along an eutrophication gradient, Barbados, West Indies. Mar. Ecol. Prog. Ser. 77: 261-269.

Tribollet, A.D. and P.S. Vroom. 2007. Temporal and spatial comparison of the relative abundance of macroalgae across the Mariana archipelago between 2003 and 2005. Phycologia 46: 187-197.

Tupper, M. World Fish Center. Penang, Malaysia. Personal communication.

Tupper, M. In preparation. Can spillover from MPAs enhance adjacent reef fisheries?

Tupper, M. In preparation. Connectivity between MPAs and exploited reefs: the role of protected spawning aggregations in supplying recruitment to Guam's reef fishery.

Tupper, M. and T. Donaldson. 2005. Impacts of subsistence fishery on coral reef resources in the War in the Pacific National Historic Park, Guam. Report prepared for the National Park Service. 7 pp. http://www.nps.gov/wapa/parkmgmt/index.htm.

U.S. Census Bureau. 2007. U.S. Census Bureau predictions for Guam. http://www.census.gov/ipc/www/idb/.

van Beukering, P., W. Haider, M. Longland, H. Cesar, J. Sablan, S. Shjegstad, B. Beardmore, Y. Liu, and G.O. Garces. 2007. The economic value of Guam's coral reefs. Technical Report 116. The Marine Laboratory, University of Guam. Mangilao, Guam. 120 pp.

Veron, J.E.N. 2000. Corals of the world, Vol. 3. Australian Institute of Marine Science. Townsville, Australia. 490 pp.

Vetter, O.J. 2007. Setup observations over two fringing reefs: Mokuleia Reef, Oahu and Ipan Reef, Guam. Masters Thesis. University of Hawaii at Manoa. Honolulu, HI.

Ward, S. and P. Harrison. 1997. The effects of elevated nutrient levels on settlement of coral larvae during the ENCORE experiment, Great Barrier Reef, Australia. pp. 891-896. In: H.A. Lessios and I.G. Macintyre (eds.). Proceedings of the 8th International Coral Reef Symposium, Vol. 1. Panama City, Panama. 1040 pp.

Ward, S. and P. Harrison. 2000. Changes in gametogensis and fecundity of acroporid corals that were exposed to elevated nitrogen and phosphorous during the ENCORE experiment. J. Exp. Biol. Ecol. 246: 179-221.

Willis, B., C.A. Page, and E.A. Dinsdale. 2004. Chapter 3. Coral disease on the Great Barrier Reef. Pages 69-103. In: E. Rosenberg and Y. Loya (eds.). Coral Health and Disease. Springer. Berlin, Heidelberg, New York. 488 pp.

Wittenberg, M. and W. Hunte. 1992. The effect of eutrophication and sedimentation on juvenile corals. Mar. Biol. 112: 131-138.

Wolanski, E., R.H. Richmond, G. Davis, and V. Bonito. 2003. Water and fine sediment dynamics in transient river plumes in a small, reef-fringed bay, Guam. Est. Coast. Shelf Sci. 56: 1029-1043.

Wolfram, M. Pacific Islands Office, U.S. Environmental Protection Agency. San Francisco, CA. Personal communication.

Zeller, D., S. Booth, G. Davis, and D. Pauly. 2007. Re-estimation of small-scale fishery catches for U.S. flag-associated island areas in the western Pacific: the last 50 years. Fish. Bull. 105(2): 266-277.

# The State of Coral Reef Ecosystems of Palau

Sebastian Marino[1], Andrew Bauman[2], Joel Miles[2], Ann Kitalong[3], Asap Bukurou[4], Charlene Mersai[1], Eric Verheij[5], Ilebrang Olkeriil[6], Kliu Basilius[7], Patrick Colin[8], Sharon Patris[8], Steven Victor[1], Wayne Andrew[9], Joel Miles[2] and Yimnang Golbuu[1]

## INTRODUCTION AND SETTING

This report is one of several that describe the status of Palau's coral reefs. In 2005, Golbuu et al. provided an overview of Palau's complex marine habitats stretching from Ngaruangel Atoll in the north to Helen Reef Atoll in the south. The overview also identified potential threats to Palau's coral reefs, including the Rock Islands south of the main island of Koror. In 2007, Kayanne et al. (2007) provided an overview of the different habitats in Palau. As in many other locations, Palauans face challenges in their efforts to protect their rich marine resources and continue to seek solutions that will mitigate threats from different sources.

Palau has an abundance of coral reef habitat types, as well as complex marine habitats associated with coral reefs including mangroves, seagrass beds, deep algal beds, mud basins, current swept lagoon bottoms and rich tidal channels. No description of Palau would be complete without mention of Palau's 70 famous marine lakes in the Rock Islands. According to Yukihira et al. (2007), the total area of coral reefs in Palau is approximately 525 km$^2$, which includes barrier reefs (264.7 km$^2$), fringing reefs (194.8 km$^2$) and atoll habitats (65.0 km$^2$) with 1,457 patch reefs scattered throughout the lagoons. Figure 16.1 is a locator map with locations and reefs mentioned in this chapter. An effort to map Palau's benthic habitats using high resolution satellite imagery was completed by NOAA's Center for Coastal Monitoring and Assessment's Biogeography Branch (CCMA-BB) in 2007; the project classified marine habitats for 1,477.54 km$^2$ and estimated that coral reef and hardbottom areas cover 892 km$^2$.

Palau's rich marine environment plays an important role in generating income for Palau. Eco-tourism is perhaps the most economically important of these activities since over 80% of Palau's visitors come to dive among the coral reefs (Palau Visitors Authority, 2001).

---

1. Palau International Coral Reef Center
2. Office of Environmental Response and Coordination
3. The Environmental Inc
4. Palau Conservation Society
5 The Nature Conservancy
6. Koror State Government
7. Environmental Quality Protection Board
8. Coral Reef Research Foundation
9. Helen Reef Project

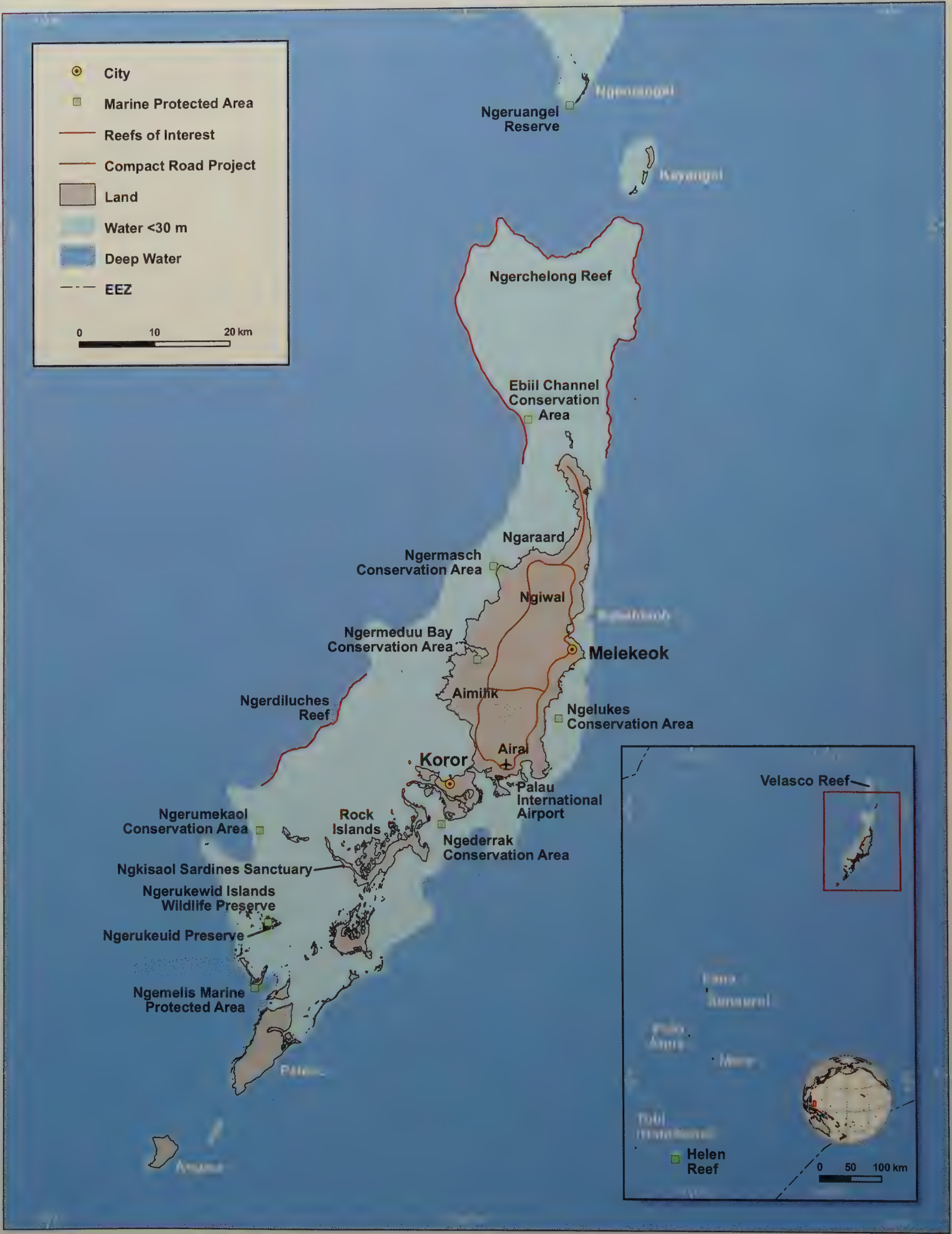

City
Marine Protected Area
Reefs of Interest
Compact Road Project
Land
Water <30 m
Deep Water
EEZ
0
10
20 km
Ngeruangel Reserve
Ngerchelong Reef
Ebiil Channel Conservation Area
Ngaraard
Ngermasch Conservation Area
Ngiwal
Ngermeduu Bay Conservation Area
Melekeok
Ngerdiluches Reef
Aimiliik
Ngelukes Conservation Area
Airai
Koror
Palau International Airport
Ngerumekaol Conservation Area
Rock Islands
Ngederrak Conservation Area
Ngkisaol Sardines Sanctuary
Ngerukewid Islands Wildlife Preserve
Ngerukeuid Preserve
Ngemelis Marine Protected Area
Velasco Reef
Helen Reef
0
50
100 km

*Figure 16.1. Map showing the locations of places mentioned in this chapter. Map: K. Buja.*

## ENVIRONMENTAL AND ANTHROPOGENIC STRESSORS

### Climate Change and Coral Bleaching

Since the 1997-1998 El Niño event, which was described by Golbuu et al. (2005), Palau has not experienced any major bleaching events. However, there have been reports of localized bleaching in different parts of Palau that are believed to be related to human impacts.

### Diseases

In the past several decades, the increasing prevalence of coral diseases worldwide has become one of the major threats challenging the resilience of coral reef communities (Harvell et al., 1999; Willis et al., 2004). In the Indo-Pacific, very little is known about the ecology and pathology of coral disease despite the fact that the region encompasses more than 80% of the earth's coral reefs (Bryant et al., 1998).

The first ecological surveys of coral disease prevalence on Palau reefs were carried out in January 2004 as part of the World Bank Global Environment Facility's Targeted Coral Reef Research Project. The purpose of the surveys was to identify and establish baseline information for coral disease at sites representative of the major habitat and community types in Palau. Results from these initial surveys indicate that the mean prevalence of coral disease was relatively low, affecting between 1 and 5.28% of colonies at six sites representative of protected, moderately exposed and exposed communities. A total of twelve diseases and syndromes were recorded from across thirteen reefs surveyed during preliminary site selection visits or disease prevalence surveys (Tables 16.1 and 16.2). Eight of these syndromes have been previously observed on Indo-Pacific reefs, in particular on the Great Barrier Reef (Willis et al., 2004). However, bleached patches, bleached spots, bleached stripe and yellow spot have not yet been recorded. At each of the six survey sites, approximately five to nine diseases or syndromes were observed. The greatest number of diseases or syndromes, nine, were recorded at the Malakal Harbor spawning site (Willis pers., comm.).

*Table 16.1. Description of disease states and syndromes recorded on Palau reefs in January 2004. Source: Willis, pers. comm.*

| DISEASE STATE/SYNDROME | DESCRIPTION |
|---|---|
| Black Band Disease (BBD) | Cyanobacterial mat forming a band that is characteristically black in color. |
| Other Cyanobacteria (O. Cyano) | Cyanobacterial mat forming a band that may be red, rust, brown, dark green etc. in color. |
| Brown Band (BrB) | Band of ciliates on recently exposed skeleton immediately behind healthy tissue front that is brown when ciliate densities are high or tan or white when densities are low. |
| Skeletal Eroding Band (SEB) | Black band of ciliates (*Halofolliculina corallasia*) that may appear speckled at edge of band distal to live tissue front because of the ciliates' abandoned black loricae. Skeleton is commonly eroded. |
| White Syndrome (WS) | White band of recently exposed skeleton, narrower than a crown-of-thorns feeding scar and more regular than a *Drupella* feeding scar. |
| Bleached | Distinct paling of tissue in part or all of a coral colony, which in extreme cases appears white. Partial bleaching may involve irregular sections of colonies where paler tissues grade into normal colored tissues. |
| Bleached Patches | Moderate-sized areas of white tissue sharply demarcated from normal colored tissues. Areas often rectangular. |
| Bleached Spots | Small areas of white tissue sharply demarcated from normal colored tissues. Areas often circular. |
| Bleached stripe | Area of white tissue, sharply demarcated from normal colored tissue in a strikingly straight line. Only recorded on *Pachyseris speciosa*. |
| Patchy Necrosis | Areas where tissue is necrosing and lifting off skeleton. Necrotic areas generally surrounded by healthy tissue in locations distant from potentially competing organisms. |
| Yellow Spot | Areas of generally necrotic tissue surrounded by intact tissue that has a yellow tinge. Only seen on massive *Porites sp.* |
| Tumor | Raised, often spherical masses projecting above the surface of the colony. Only recorded on *Acropora* species, where they manifested as bleached neoplasms, which have few discernible polyp or corallite features. |

Table 16.2. Diseases/syndromes recorded on and off of six transects in Palau in January 2004. Source: Willis pers. comm.

| | NIKKO BAY SPAWNING | NIKKO BAY | MALAKAL HARBOUR SPAWNING | KELTARIR | WESTERN BARRIER NGATBANG | WESTERN BARRIER NGEREMLENGUI |
|---|---|---|---|---|---|---|
| **Disease States Recorded on Transects** | | | | | | |
| Black Band Disease | | | | | | |
| Brown Band Disease | | | x | x | | |
| Skeletal Eroding Band | x | x | x | x | x | x |
| Other Cyanobacterial Infections | x | x | x | x | x | x |
| Bleached Spots | x | x | x | x | x | x |
| Bleached Patches | x | x | x | x | x | x |
| Bleached Stripe | x | | | | | |
| White Syndrome | x | x | x | x | | |
| Patchy Necrosis | x | x | | | | x |
| Yellow spot | | | | | x | |
| Tumours | | | x | x | x | |
| **Disease States Recorded off Transects** | | | | | | |
| Black Band Disease | | | x | | | |
| Other Cyanobacterial infections | x (red) | | | | | |
| Yellow spot | | | x | x | | |

## Tropical Storms

Tropical storms are common in Palau. The outer reef slope is much more susceptible to physical damage to corals from from tropical storm surge and large waves. Consequently, many of Palau's fore reefs are dominated by encrusting and massive forms of coral species (Golbuu et al., 2005). No directed studies have been conducted to quantify the effects of tropical storms on the coral habitats of Palau.

Since the last report, no major storms or typhoons have passed through Palau (Figure 16.2).

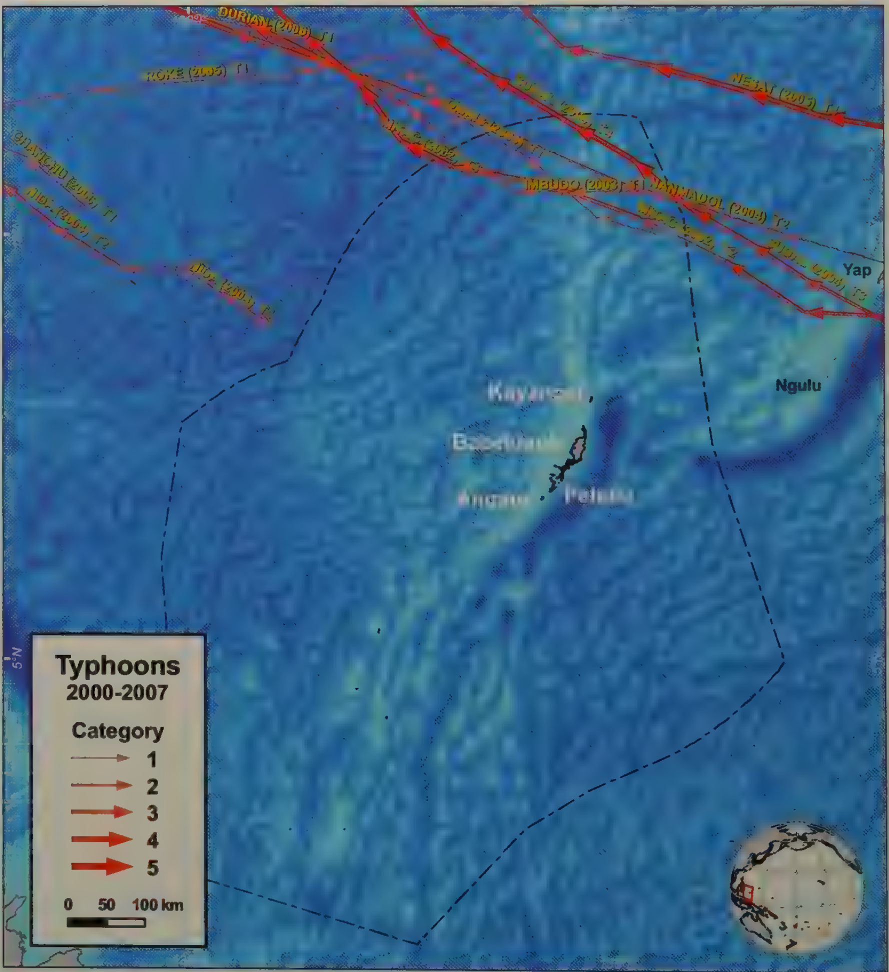


Figure 16.2. The paths, name, year and intensities of typhoons passing near Palau from 2000 to 2007. Map: K. Buja. Source: http://weather.unisys.com/hurricane/.

## Coastal Development and Runoff

During the three-year period covered by this report, coastal development and runoff have increasingly become areas of concern. This reporting period has seen many changes regarding demographic shifts, permitting and construction, road building, sedimentation, land use and land use changes. Most of these changes are a result of the construction and completion of the compact road encircling Babeldaob Island, as well as the resulting move of the central government from Koror State to Melekeok State on Babeldaob.

Demographically speaking, Palau has seen a shift in population as people who once resided in Koror have increasingly moved back to their home villages and states in

Babeldaob. Since the central government officially opened for operations in October 2006, no census data has been collected to quantify this shift. Other concerns related to the return of numerous Palauans to Babeldaob include changes in land use, and to a lesser degree, construction and permitting. In addition to road building and resulting sedimentation, a large number of new residences have been constructed. Often this has required the construction of secondary roads for access.

The Environmental Quality Protection Board (EQPB) permitting process covers public and private projects such as housing projects, road constructions, hotels, docks, dredging and other large government infrastructure projects. Large commercial projects with significant environmental impacts are required to prepare to environmental impact assessments/ environmental impact statements in accordance with Palau's Environmental Quality Protection Act.

The EQPB reviewed and approved the Environmental Protection Plan (EPP) prepared and submitted by Daewoo prior to construction of the compact road. The EPP outlines the impacts and mitigation measures that the contractor needs to implement prior to and during construction of the road. In addition, EQPB's compact road inspector conducted regular monitoring of the contractor's work areas and facilities to ensure that the mitigation measures were properly implemented and in compliance with the EPP and EQPB permit and regulations.

Both the state governments and private contractors involved in secondary road construction are required to properly implement Erosion and Sedimentation Control Plans. These erosion controls, both temporary and permanent (such as silt tank, earth/rock berm, slope protection, hydroseeding) are measures necessary to prevent or minimize erosion problems in the area. Basic installation and maintenance procedures for erosion control structures are already in place at EQPB.

Measures are being undertaken to have all state access roads paved in the long term. Presently, with the exception of the compact road, all access roads in Babeldaob are unpaved and sediments are continually washed into streams and marine waters.

### Coastal Pollution

There are quite a few point source pollution sources in Palau. Major industries in coastal areas that contribute marine pollution and coastal area degradation include fishing companies and hotels. Fishing companies discharge brine, oil and trash such as fishing lines, trash and sewage from ships moored at their docks.

There are roughly ten fueling stations that are near, if not adjacent to, the water. No reports of adverse problems have been reported due to major spills of oil or other pollutants from these stations. Still, the cumulative effects of small spills may damage nearby coral reefs and marine life.

There are also challenges related to the Koror State landfill and pollution of nearby waters from contaminated leachate. Work is ongoing to rehabilitate the M-Dock Landfill through construction of a new anaerobic sanitary landfill.

The public sewer system that exists in Palau is over 25 years old and has deteriorated due to a lack of maintenance. Sewage overflows are reported by the public at least twice per week. This affects water quality in the immediate vicinity of the overflow by contaminating the area with bacteria, which adversely affects the water quality and increases the concentrations of nitrates and phosphates. Plans are underway by the Ministry of Resources and Development to upgrade the whole system by improving the major pump stations at the Capital Improvement Project (CIP) and Malakal.

Improper farming methods and unplanned road construction are some of the common sources of coastal pollution (Victor et al., 2004). One of the challenges that the EQPB faces is regulating earthmoving activities that have not been permitted. When these activities take place without control measures in place, implementation of corrective measures are often lengthy and costly.

### Tourism and Recreation

Tourism remains the primary source of revenue for Palau and the government is pursuing an approach to attract higher-income tourists to Palau. Local governments and communities see the potential of tourism as a continued source of income generation. In 2005, 80,578 tourists visited Palau, while 82,397 visited in 2006 (Tables 16.3 and 16.4). This steady increase of visitors to Palau could represent a serious threat to the marine environment and coral reef areas, but Palauans are taking action to prevent some damage. In 2006, Peleliu State placed more mooring buoys around the island at known dive sites to minimize damage to the coral reefs. In addition, the introduction of a sea anemone (*Aiptasis* sp.) into Jellyfish Lake in 2003 prompted Koror State to take precautionary measures and amend the Rock Island Use Act of 1997. The amendment established zoning for the Rock Islands and created a new fee schedule to help mitigate impact at sensitive tourist sites.

Many communities on the big island of Babeldaob are taking advantage of the increase in tourism and the opening of the new road to develop land-based activities for visitors. In 2007,a river boat tour business began operations in Ngchesar State on the big island of Babeldaob. There has also been an increase in the number of tourists visiting waterfalls and other historical sites on Babeldaob Island. Still, the vast majority of visitors to Palau come to dive, snorkel and visit the famous Rock Islands.

Table 16.3. 2005 visitor breakdown by country of origin. Source: PVA.

| | JAN | FEB | MAR | APRIL | MAY | JUNE | JULY | AUG | SEPT | OCT | NOV | DEC | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| AUS / NZ | 72 | 46 | 42 | 95 | 65 | 80 | 94 | 61 | 83 | 87 | 44 | 49 | 818 |
| GERMANY | 80 | 104 | 110 | 55 | 46 | 22 | 26 | 17 | 16 | 47 | 51 | 32 | 606 |
| GUAM | 228 | 231 | 344 | 200 | 289 | 288 | 477 | 200 | 170 | 177 | 237 | 171 | 3,012 |
| HONG KONG | 16 | 108 | 58 | 47 | 71 | 24 | 132 | 455 | 82 | 278 | 39 | 77 | 1,387 |
| ITALY | 26 | 22 | 40 | 23 | 22 | 3 | 8 | 68 | 4 | 2 | 19 | 47 | 284 |
| JAPAN | 3,003 | 2,829 | 2,605 | 1,673 | 1,621 | 834 | 2,233 | 2,841 | 2,630 | 1,447 | 1,570 | 2,995 | 26,281 |
| KOREA | 1,292 | 471 | 18 | 25 | 19 | 31 | 27 | 33 | 6 | 29 | 22 | 196 | 2,169 |
| MICRONESIA | 209 | 128 | 140 | 104 | 160 | 223 | 716 | 128 | 95 | 104 | 201 | 84 | 2,292 |
| PHILIPPINES | 76 | 38 | 79 | 66 | 68 | 58 | 68 | 66 | 43 | 70 | 82 | 62 | 776 |
| PRC CHINA | 49 | 44 | 16 | 20 | 24 | 22 | 38 | 39 | 8 | 38 | 16 | 22 | 336 |
| ROC TAIWAN | 2,755 | 2,999 | 2,469 | 3,134 | 2,846 | 3,116 | 3,871 | 3,667 | 2,752 | 2,388 | 2,121 | 1,983 | 34,101 |
| RUSSIA | 37 | 42 | 23 | 17 | 15 | 1 | - | - | - | 80 | 43 | 10 | 268 |
| SWITZERLAND | 27 | 11 | 40 | 25 | 18 | 7 | 2 | 6 | 5 | 19 | 15 | 13 | 188 |
| UNITED KINGDOM | 21 | 16 | 42 | 7 | 27 | 27 | 14 | 19 | 14 | 42 | 23 | 40 | 292 |
| US MAINLAND | 564 | 610 | 518 | 494 | 375 | 453 | 463 | 292 | 306 | 424 | 538 | 495 | 5,532 |
| OTHER EUROPE | 72 | 82 | 70 | 82 | 3 | 41 | 55 | 47 | 23 | 56 | 71 | 49 | 651 |
| OTHERS | 54 | 97 | 85 | 90 | 134 | 77 | 737 | 48 | 23 | 80 | 114 | 46 | 1,585 |
| **TOTAL** | **8,581** | **7,878** | **6,699** | **6,157** | **5,803** | **5,307** | **8,961** | **7,987** | **6,260** | **5,368** | **5,206** | **6,371** | **80,578** |

Table 16.4. 2006 visitor breakdown by country of origin. Source: PVA.

| | JAN | FEB | MAR | APRIL | MAY | JUNE | JULY | AUG | SEPT | OCT | NOV | DEC | TOTAL | FY'06 YTD** vs. FY'05 YTD** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| AUS / NZ | 52 | 28 | 46 | 75 | 92 | 34 | 82 | 23 | 50 | 50 | 36 | 28 | 596 | -27.14% |
| GERMANY | 43 | 89 | 112 | 66 | 28 | 10 | 7 | 24 | 20 | 21 | 47 | 47 | 514 | -15.18% |
| GUAM | 170 | 176 | 158 | 218 | 107 | 197 | 239 | 185 | 195 | 86 | 134 | 174 | 2,039 | -32.30% |
| HONG KONG | 62 | 11 | 20 | 69 | 22 | 18 | 22 | 23 | 34 | 40 | 11 | 60 | 392 | -71.74% |
| ITALY | 29 | 72 | 43 | 34 | 4 | 2 | 11 | 55 | 3 | 28 | 21 | 42 | 344 | 21.13% |
| JAPAN | 2,898 | 2,876 | 3,070 | 1,684 | 1,423 | 772 | 2,318 | 2,905 | 2,793 | 1,530 | 1,441 | 3,182 | 26,892 | 2.32% |
| KOREA | 920 | 1,207 | 240 | 729 | 1,173 | 1,334 | 1,336 | 1,069 | 181 | 1,145 | 1,064 | 1,358 | 11,756 | 442.00% |
| MICRONESIA | 52 | 85 | 96 | 106 | 128 | 93 | 393 | 82 | 91 | 81 | 92 | 138 | 1,437 | -37.30% |
| PHILIPPINES | 50 | 53 | 65 | 233 | 173 | 147 | 94 | 137 | 120 | 135 | 77 | 146 | 1,430 | 84.28% |
| PRC CHINA | 43 | 16 | 18 | 50 | 54 | 8 | 20 | 30 | 30 | 42 | 18 | 57 | 386 | 14.88% |
| ROC TAIWAN | 2,084 | 2,877 | 2,641 | 2,393 | 2,293 | 2,354 | 2,821 | 2,652 | 2,152 | 2,317 | 1,781 | 2,084 | 28,449 | -16.57% |
| RUSSIA | 40 | 9 | 21 | 63 | 31 | 2 | 4 | - | 4 | 52 | 81 | 9 | 316 | 17.91% |
| SWITZERLAND | 18 | 13 | 27 | 20 | 9 | 3 | 6 | 4 | 13 | 19 | 31 | 22 | 185 | -1.60% |
| UNITED KINGDOM | 19 | 25 | 36 | 40 | 12 | 20 | 13 | 11 | 20 | 9 | 14 | 20 | 239 | -18.15% |
| US MAINLAND | 464 | 596 | 640 | 721 | 498 | 462 | 566 | 331 | 274 | 381 | 597 | 392 | 5,922 | 7.05% |
| OTHER EUROPE | 54 | 86 | 86 | 92 | 21 | 8 | 38 | 42 | 30 | 81 | 71 | 56 | 665 | 2.15% |
| OTHERS | 52 | 34 | 55 | 94 | 93 | 43 | 141 | 53 | 78 | 51 | 74 | 67 | 835 | -47.32% |
| TOTAL | 7,050 | 8,253 | 7,374 | 6,687 | 6,161 | 5,507 | 8,111 | 7,626 | 6,088 | 6,068 | 5,590 | 7,882 | 82,397 | 2.26% |

**FY06/MO versus FY05/MO=FISCAL 2006 MONTHLY versus FISCAL 2005 MONTHLY.*
***YTD stands for year to date*

## Fishing

### *Inshore Fisheries Production*

The fishery industry in Palau is a dynamic, multi-species industry involving individual fishers feeding their families, providing food for traditional customs and selling to commercial markets, restaurants and selective buyers for export. Between 1989 and 1998, Palau's total inshore fisheries production was estimated at 2,155 metric tons (mt) from 1,000 fishers with 800 boats (TEI, 1999). An estimated 400 mt (19%) was exported either directly by the fishers, residents or through retailers and wholesalers. An estimated 1,715 mt (81%) was consumed locally (TEI, 1999; PCS, 2000). Palau's reef yield was estimated at one million metric tons of fish and invertebrates over the span of 100 years (TEI, 1999). This value is based upon an average total production of 1,800 mt/km$^2$ for a total reef and lagoon area of 1,706 km$^2$. The total maximum yield from the reefs between the periods of 1992 to 1997 and 1998 to 2001 showed a decline in yield for nine states: Aimeliik, Airai, Angaur, Ngaraard, Ngarchelong, Ngardmau, Ngatpang, Ngchesar and Ngiwal. This decline may be attributed to several factors including the presence of large-scale pulse fishing operations, coral bleaching, loss of habitat and sedimentation from land based activities. New management regulations through the 1994 Marine Protection Act may also explain the decline in specific fisheries (TEI, 2003).

*The 1994 Marine Protection Act*

The 1994 Marine Protection Act was established to better manage the local fisheries. Specific management tools described in this Act include: bans on export of certain species (e.g., mangrove crab, specific species of sea cucumber); closed harvest seasons (the rabbitfish, *S. fuscescens* and groupers, *Epinephelus* and *Plectropomus* spp.); size limits (*Cheilinus*, *Bolbometopon*, crabs, lobsters); and mesh size limits for nets and permit requirements for aquaculture and aquarium trade ventures. Legislative attempts to implement complete bans on certain species and extend moratoriums of endangered species have been met with limited success.

*Annual Variation in Production*

Annual variation in landing for any given fishery is complex in nature. Cyclic patterns based upon climate conditions and good recruitment years may occur. Seasonal closures during peak spawning may also be peak fishing periods and thus reduce landings (such as the 1994 Marine Act). Overfishing and pollution may alter important marine habitats and reduce catch rates. Lack or loss of data from a major fish market may be a factor causing variability as well. All these factors may in part explain annual variations in landings for a specific fishery such as the mottled spinefoot (*Siganus fuscescens).*

*Mangrove Crab*

Mangrove crab (*Scylla serrata*) is the top crustacean sold commercially. From 1989 to 1998, the mean annual production averaged at 24 mt with yields of 0.5 mt/km². (TEI, 2003) The mangrove crab fishery peaked in the early 1990s when a commercial venture in Ngatpang State was in full production. In 1994, the Marine Protection Act 27 Palau National Code Annotated 1204 was enacted and imposed a minimum size limit of six inches across the carapace and a ban on their export. The following few years showed a decline in sales that may reflect a decrease in export sales. In 1998, domestic market sales increased but there was a trend of steady decrease over the next seven years (BMR, 2005). Ecological, economical and social studies are needed to understand the dynamics of a given fishery.

*Trochus*

For the past 100 years, *Trochus niloticus* has been the top mollusk collected in Palau. However, over the past decade, the average annual landing of *Trochus* is at 200 mt. Management has consisted of size limits, sanctuaries, three-year moratoriums, a short (one-month) harvest season and a very specific export market. Such protective multi-pronged management approaches should be implemented for other marine resources.

*Market Survey Data*

In the 1970s, the Palau Federation of Fishing Association (PFFA) was the main distributor of fish both locally and internationally. PFFA was government-operated, which helped make data collection more efficient and complete. Over the years, fish distribution has become less centralized and smaller markets experience shifts in sales based upon the fisher's preference and the buyer's incentives. These markets are not required by law to provide information to Palau's Bureau of Marine Resources (BMR). Consequently, sales are reported based upon price categories and not individual species of fish. Over the last three decades, the quality of data has varied and the percentage of market information captured has varied from 30 to 85%. Often data is outdated or non-existent for many species. More studies are needed to implement appropriate management strategies for specific species.

*Data Collection*

In the past decade, the BMR has set up a data collection program to track fish exports at the species level; this program provides the most reliable source of information for exported fish. The purposes of collecting data is to determine relative abundance of a resource, develop effective management tools for both the informal and commercial fishery and draft legislation to guide the implementation of effective management practices. The BMR requires that all exporters submit a report with detailed information on the name, number and weight of all fish and invertebrate species and other organisms being exported by air. In addition the BMR collects data from local fisheries markets. Unfortunately, nearly 33% of species are lumped into the "assorted fish" category that is based on price. Market data is also being collected to track sales to hotels, restaurants and individuals in the communities. Maintaining a database and archiving data is critical to look at a long-term trends in a given fishery. Example results from these efforts are provided in Tables 16.5 and 16.6.

*Fisheries Management*

The goal of any fisheries management strategy is to sustain a resource over time. Resource studies are needed in order to assess the efficacy of management actions and determine what management approaches are most effective. Banning exports, setting size limits and implementing closed seasons in an effort to manage specific resources requires studies before, during and after a restriction to establish baseline data. From there, the consequences activities have on the resource can be studied. Setting restrictions on one resource can also shift fishing pressure to another species that must also be monitored. Parrotfish, (*Bolbometopon muricatum*, kemedukl), groupers (*Epinephelus* spp.) and rabbitfish (*Siganus fuscescens*) were top commercial species between 1992 and 2005 (BMR, unpub. data). However, a ban on commercial sale of parrotfish and closures during the spawning seasons for groupers and rabbitfish *have* shifted fishing effort toward fish for which there are no restrictions, such as bluespine unicornfish (*Naso unicornis).* Bluespine unicornfish

Table 16.5. 2000-2004 fisheries landing data by state. Source: Palau Department of Planning and Statistics.

| State | Year | Reef fish (lbs) | Reef Fish Value | Tuna and Mackerel (lbs) | Tuna and Mackerel Value | Crabs (lbs) | Crabs Value | Lobster (lbs) | Lobster Value | Trochus (lbs) | Trochus Value |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Aimeliik | 2000 | 2636 | $3,401.00 | | | 137 | $481.00 | | | 509 | $509.00 |
| | 2001 | 2856 | $3,650.00 | | | 197 | $763.00 | | | | |
| | 2002 | 9301 | $12,245.00 | 97 | $49.00 | 47 | $186.00 | 77 | $296.00 | | |
| | 2003 | 4070 | $5,170.00 | 156 | $203.00 | 164 | $956.00 | | | | |
| | 2004 | 111180 | $14,805.00 | 19 | $21.00 | 216 | $1,213.00 | | | | |
| Airai | 2000 | 730 | $949.00 | 171 | $167.00 | 3031 | $12,003.00 | | | 740 | $740.00 |
| | 2001 | 2431 | $3,010.00 | 224 | $246.00 | 3221 | $12,946.00 | 2 | $8.00 | | |
| | 2002 | 9797 | $12,594.00 | 425 | $375.00 | 2390 | $14,365.00 | 35 | $124.00 | | |
| | 2003 | 43416 | $58,768.00 | 747 | $971.00 | 1596 | $7,928.00 | 436 | $1,679.00 | | |
| | 2004 | 46993 | $67,667.00 | 294 | $354.00 | 1607 | $9,423.00 | | | | |
| Angaur | 2000 | 235 | $235.00 | | | 18 | $61.00 | | | 1549 | $1,549.00 |
| | 2001 | 1275 | $1,477.00 | | | 77 | $308.00 | 27 | $100.00 | | |
| | 2002 | 4449 | $5,657.00 | 133 | $133.00 | | | 14 | $45.00 | | |
| | 2003 | 43416 | $58,768.00 | 747 | $971.00 | 1596 | $7,928.00 | 436 | $1,679.00 | | |
| | 2004 | | | | | | | | | | |
| Kayangel | 2000 | 2187 | $2,368.00 | | | | | | | 41761 | $41,761.00 |
| | 2001 | 1162 | $1,335.00 | 498 | $548.00 | | | 37 | $134.00 | | |
| | 2002 | 2876 | $3,467.00 | 1015 | $1,063.00 | | | | | | |
| | 2003 | 261 | $287.00 | 99 | $109.00 | | | | | | |
| | 2004 | 22487 | $26,670.00 | 214 | $246.00 | | | 3 | $15.00 | | |
| Koror | 2000 | 200209 | $263,851.00 | 2302 | $2,380.00 | 3455 | $12,411.00 | 491 | $1,882.00 | 229351 | $231,210.00 |
| | 2001 | 179250 | $221,453.00 | 6876 | $6,972.00 | 4036 | $15,480.00 | 853 | $3,052.00 | | |
| | 2002 | 259374 | $346,813.00 | 7347 | $5,682.00 | 2221 | $8,892.00 | 1844 | $6,609.00 | | |
| | 2003 | 275477 | $375,047.00 | 18671 | $20,791.00 | 2129 | $10,594.00 | 1185 | $4,208.00 | | |
| | 2004 | 228300 | $310,053.00 | 12540 | $14,495.00 | 2964 | $17,831.00 | 29 | $109.00 | | |
| Melekeok | 2000 | 57 | $74.00 | | | | | | | 10782 | $10,782.00 |
| | 2001 | 5430 | $6,302.00 | 54 | $59.00 | | | 32 | $120.00 | | |
| | 2002 | 11594 | $12,693.00 | | | 22 | $88.00 | | | | |
| | 2003 | 16151 | $20,013.00 | 2060 | $2,415.00 | | | 41 | $156.00 | | |
| | 2004 | 10566 | $13,105.00 | 717 | $932.00 | | | | | | |
| Ngatpang | 2000 | 16931 | $16,605.00 | | | 1005 | $3,948.00 | 30 | $94.00 | 3489 | $3,489.00 |
| | 2001 | 12206 | $13,046.00 | 190 | $162.00 | 255 | $982.00 | 26 | $81.00 | | |
| | 2002 | 22139 | $27,004.00 | 483 | $531.00 | 788 | $3,161.00 | | | | |
| | 2003 | 10403 | $13,423.00 | 5 | $72.00 | 401 | $1,817.00 | | | | |
| | 2004 | 13324 | $16,232.00 | 159 | $207.00 | 168 | $979.00 | | | | |
| Ngiwal | 2000 | 819 | $1,081.00 | | | | | | | 3591 | $3,591.00 |
| | 2001 | 3974 | $5,192.00 | | | 378 | $1,432.00 | 48 | $168.00 | | |
| | 2002 | 2427 | $3,068.00 | 142 | $107.00 | 1010 | $4,302.00 | 23 | $90.00 | | |
| | 2003 | 1331 | $1,731.00 | | | 456 | $2,379.00 | 2 | $8.00 | | |
| | 2004 | 272 | $366.00 | 329 | $428.00 | 459 | $2,600.00 | | | | |
| Ngerchelong | 2000 | 6941 | $7,604.00 | | | 248 | $990.00 | 4 | $16.00 | 36269 | $36,269.00 |
| | 2001 | 16479 | $18,105.00 | 502 | $542.00 | 1091 | $4,349.00 | 13 | $50.00 | | |
| | 2002 | 37013 | $49,517.00 | 615 | $557.00 | 850 | $3,390.00 | 25 | $98.00 | | |
| | 2003 | 6227 | $7,889.00 | 25 | $33.00 | 26 | $132.00 | | | | |
| | 2004 | 6991 | $87,723.00 | | | 26 | $155.00 | | | | |

Table 16.6. 2000-2004 fish survey (continued). Source: Palau Department of Planning and Statistics.

| State | Year | Reef fish (lbs) | Reef Fish Value | Tuna and Mackerel (lbs) | Tuna and Mackerel Value | Crabs (lbs) | Crabs Value | Lobster (lbs) | Lobster Value | Trochus (lbs) | Trochus Value |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Ngaraard | 2000 | 92309 | $92,331.00 | 6556 | $5,308.00 | 6406 | $23,621.00 | 888 | $3,207.00 | 72344 | $728,119.00 |
| | 2001 | 3637 | $4,472.00 | | | 90 | $358.00 | 121 | $449.00 | | |
| | 2002 | 6881 | $9,277.00 | | | 391 | $1,574.00 | 19 | $74.00 | | |
| | 2003 | 2993 | $4,169.00 | | | 726 | $3,597.00 | 20 | $80.00 | | |
| | 2004 | 8630 | $11,758.00 | | | 379 | $2,011.00 | | | | |
| Ngarmlengui | 2000 | 92309 | $92,331.00 | 6556 | $5,308.00 | 6406 | $23,921.00 | 888 | $3,207.00 | 72344 | $72,819.00 |
| | 2001 | 32374 | $33,983.00 | 2849 | $2,957.00 | 7195 | $26,833.00 | 613 | $1,868.00 | | |
| | 2002 | 25129 | $32,103.00 | 948 | $709.00 | 2703 | $11,434.00 | 145 | $573.00 | | |
| | 2003 | 22329 | $244,011.00 | 3237 | $3,896.00 | 1362 | $5,663.00 | 105 | $324.00 | | |
| | 2004 | 25321 | $29,545.00 | 3965 | $4,801.00 | 1510 | $7,312.00 | 80 | $309.00 | | |
| Ngchesar | 2000 | 2254 | $2,876.00 | 226 | $233.00 | 24 | $96.00 | | | 943 | $943.00 |
| | 2001 | 9271 | $11,731.00 | 1139 | $1,215.00 | 369 | $1,434.00 | | | | |
| | 2002 | 4360 | $5,514.00 | 161 | $139.00 | 340 | $1,358.00 | 52 | $208.00 | | |
| | 2003 | 922 | $1,228.00 | 126 | $102.00 | 371 | $1,926.00 | | | | |
| | 2004 | 545 | $629.00 | | | 141 | $817.00 | | | | |
| Ngardmau | 2000 | 12858 | $16,772.00 | | | 215 | $850.00 | 18 | $85.00 | 4341 | $4,402.00 |
| | 2001 | 8646 | $11,207.00 | | | 128 | $504.00 | 56 | $233.00 | | |
| | 2002 | 14581 | $20,479.00 | | | 297 | $1,195.00 | 92 | $346.00 | | |
| | 2003 | 13427 | $18,253.00 | | | 724 | $3,514.00 | 96 | $369.00 | | |
| | 2004 | 19006 | $25,739.00 | | | 946 | $5,592.00 | | | | |
| Peleliu | 2000 | 26443 | $27,543.00 | 1471 | $1,388.00 | 23 | $92.00 | | | 46299 | $46,360.00 |
| | 2001 | 37247 | $48,043.00 | 1242 | $1,024.00 | 283 | $1,130.00 | 98 | $386.00 | | |
| | 2002 | 22784 | $24,753.00 | 1604 | $1,440.00 | 114 | $456.00 | | | | |
| | 2003 | 18231 | $19,471.00 | 4070 | $3,510.00 | 21 | $84.00 | 20 | $76.00 | | |
| | 2004 | 16332 | $17,295.00 | 1029 | $875.00 | 25 | $149.00 | | | | |
| Unkown | 2000 | 1585 | $2,126.00 | | | 41 | $205.00 | | | | |
| | 2001 | 949 | $967.00 | | | 31 | $124.00 | | | | |
| | 2002 | 1418 | $1,999.00 | 102 | $58.00 | 93 | $371.00 | 9 | $36.00 | | |
| | 2003 | 92 | $92.00 | | | | | | | | |
| | 2004 | 219 | $241.00 | | | | | | | | |

has been the top commercial species for the past decade, and visual inspections of commercial landings of Bluespine unicornfish included many undersized fish (TEI, 1999). During a survey of subsistence activities in the Rock Islands, many respondents (49%) felt that current restrictions were ineffective due to poor enforcement or monitoring of catches to control the size of fish taken. Most (68%) felt that there are species that are threatened and not currently protected including the *N. unicornis* and *B. muricatum* (Matthews, 2004). It is recommended that further studies be conducted to determine the status and distribution of Palau's population of *N. unicornis*.

Seasonal closures may also concentrate fishing activity. Export data shows an increased level of fishing during pre and post closure periods that may be causing a greater impact than the closure itself (BMR database). Managers recommend extending closures if a resource continues to decline. Another management tool is to implement protected areas, but more data is needed in Palau to determine if protected areas are effective and how to regulate uses within protected area boundaries. In a multi-species fishery, it is difficult to integrate species' life histories with size limits, seasonal closures and protect habitats, which underscores the need for consultation with key stakeholders. In Palau, stakeholders are easily identified through the BMR database, which lists the fishers that sell or export fisheries resources. These individuals are potential collaborators in research to better understand life histories, behavior and habitats of a given resource.

### *Adaptive Management*

Fisheries management needs to be adaptive to changes in the natural and social environment for each resource in question. Active participation with the people most dependent upon that resource is critical. Traditional ecological knowledge in combination with sound scientific methodologies may help sustain small scale fisheries within each state. Education and awareness within communities about their resources and how to best manage and sustain them is ongoing in Palau. Decision makers need information from ongoing studies that evaluate the status of key commercial species. Monitoring programs need to include periodic habitat and market surveys to determine relative population densities and collect length and weight data to assess changes in the population structure and determine if populations are sustainable. Surveys need to be adapted to the life histories of the resource in question. One time surveys during the day provide information but we must be cautious how this information is interpreted and extrapolated. The outcome may result in a modification of management that in fact was neither necessary nor appropriate. Ongoing educational programs are needed to disseminate new information and promote a healthy exchange of information and mutual trust between the managers and the stakeholders. Stakeholders need to know why resource limitations are being implemented and if the management approach is working before they will support and assist in programs for a resource they depend on for a living. Feedback is crucial once a management strategy is implemented to determine gaps or unanticipated impacts as a result of that strategy.

*Aquaculture*

Aquaculture has been promoted for decades, yet a cost-benefit analysis of this activity has shown that it is unsustainable in Palau and would require large financial subsidies, in the form of equipment, trained personnel, marketing and supplies, for long-term maintenance. If it is national policy to support and promote aquaculture, an effective mechanism to implement and sustain aquaculture is needed. This mechanism needs to include a phasing out of subsidies and a long-term commitment to the aquaculture community to maintain and train local farmers. Stakeholders need to work with the BRM to provide data and monitoring. A commercial venture needs to devote a percentage of the profits towards the cost of restocking juvenile clams and fish species. States that are currently receiving national funds for aquaculture need to have Palauans working on site. It is important that skills are transferred and states commit funds and human resources to programs. Another issue is the loss of habitat for aquaculture. The reefs and mangroves provide natural services. Loss of mangroves and reefs make coastal communities more vulnerable to storms and wind. Site selection and cost-benefit are critical factors as well as long-term commitment.

*Vulnerable Marine Species Conservation Program*

The BMR has established the Vulnerable Marine Species Conservation Program for the endangered crocodile, turtles and dugong. The Endangered Species Act (Title 24 Palau National Code, Chapter 10) and Protected Sea Life Act (Title 24 Palau National Code Chapter 12) prohibit the harvest of dugong and crocodile and restrict turtle harvest to certain months of the year. Dugongs (*Dugong dugon*) and its habitat are protected by law. Joshua Eberdong, the Vulnerable Marine Species conservation program Coordinator at BMR, directed the flight paths for dugong surveys based on surveys conducted by The Nature Conservancy (TNC) and other scientists in 1977/1978, 1983, 1991, 1998 and 2003. In September 2007, a total of 27 dugongs (18 adults and nine calves) were spotted around Malakal Harbor and the Rock Islands. Two days later, two adult dugongs and one calf were seen on the west coast of Babeldaob (J. Eberdong and S. Klain pers. comm.; A. Kitalong pers. obs. 2007). The aerial coverage of the 2007 surveys was less than the 2003 aerial survey in which 27 individuals, 20 adults and seven calves were observed. Palau's salt water crocodile (*Crocodylus porosus*) is the only population that occurs within Micronesia. The last official survey was in 2003 and the population was estimated to be 500 to 750 non-hatchling individuals (Brazaitis et al., 2003). Crocodile monitoring and tagging is ongoing. Nuisance crocodiles are trapped and relocated to other locations within a state.

Hawksbill (*Eretmochelys imbricata*) and green turtles (*Chelonia mydas*) maintain resident and nesting populations in Palau. During 2004 and 2005, nesting green turtles were tagged at Hatohobei at Helen Reef Islet (40) and Sonsorol at Merir Islands (36). A total of 581 green turtle nests were recorded in Sonsorol (331), Hatohobei (232), Kayangel (7) and Ngarchelong (11). During 2004 and 2005, 66 hawksbill nests were found in Angaur, Peleiu, Koror, Ngaraard, Ngarchelong and Kayangel. Evidence of poaching was present for 36% of the nests (Kitalong and Eberdong, 2006). Management of turtles included size limits, closed seasons, head starting, tagging and monitoring of beaches. Head starting was discontinued because it was considered unsustainable. Conservation and monitoring are currently underway. A similar concern of increased hunting pre and post closure may have a negative impact that outweighs the closure. Enforcement and increased fines has been recommended in two national workshops. Traditionally, large species were caught in small numbers for very important customs. The Helen Reef community decided to close its turtle fishery for several years. However, this ban put increased harvesting pressure on the Sonsorol turtles. A collaborative approach with communities sharing a similar resource is recommended. Currently the capture of turtles has been excessive for both traditional and non-traditional celebrations. The women in Palau want a long-term ban on the harvest of turtle, especially hawksbill. The traditional money is made from the hawksbill shell and its value is based on size and quality of shell. The women have seen a decline in size over time. Regional collaboration is required as two green turtles with tracking devices are currently foraging in Indonesia.

## Trade in Coral and Live Reef Species

Marine ornamental trade continues to be a growing business around the world. The popularity of home aquaria that mimic coral reef ecosystems has made the live fish and marine invertebrate trade an attractive business venture (Golbuu et al., 2005). However, since the 2005 edition of this report, there has been a significant reduction in the volume of live fish, coral and other organisms exported for the aquarium trade from Palau. The only live fish and marine invertebrate trade business in Palau, Belau Aquaculture, was closed down in 2006. During this same year, a private business dealing in live fish food trade was launched. This business targeted live groupers and napoleon wrasses. The employees either fished or bought live fish from local fishermen. It was not long before the business ran into some legal problems, which lead to its closure. Although the company operated for just over six months, there was no data available on their exports.

## Ships, Boats and Groundings

Four major ship groundings have occurred in Palau since the last status report. In late October 2005, the USNS *Niagara Falls*, a 176 m long "Combat Stores Ship" with a draft of 8 m and operated by the Military Sea Lift Command, grounded on a reef 1.5-2 m deep bordering the main shipping channel while departing Palau (Figure 16.3). The vessel remained aground for two days; its forward portion resting on the reef while its stern was in deeper water of the channel. It was finally able to back off the reef at high tide on November 1, 2005. After an underwater inspection revealed no significant damage to the hull, the ship was able to steam away under its own power.

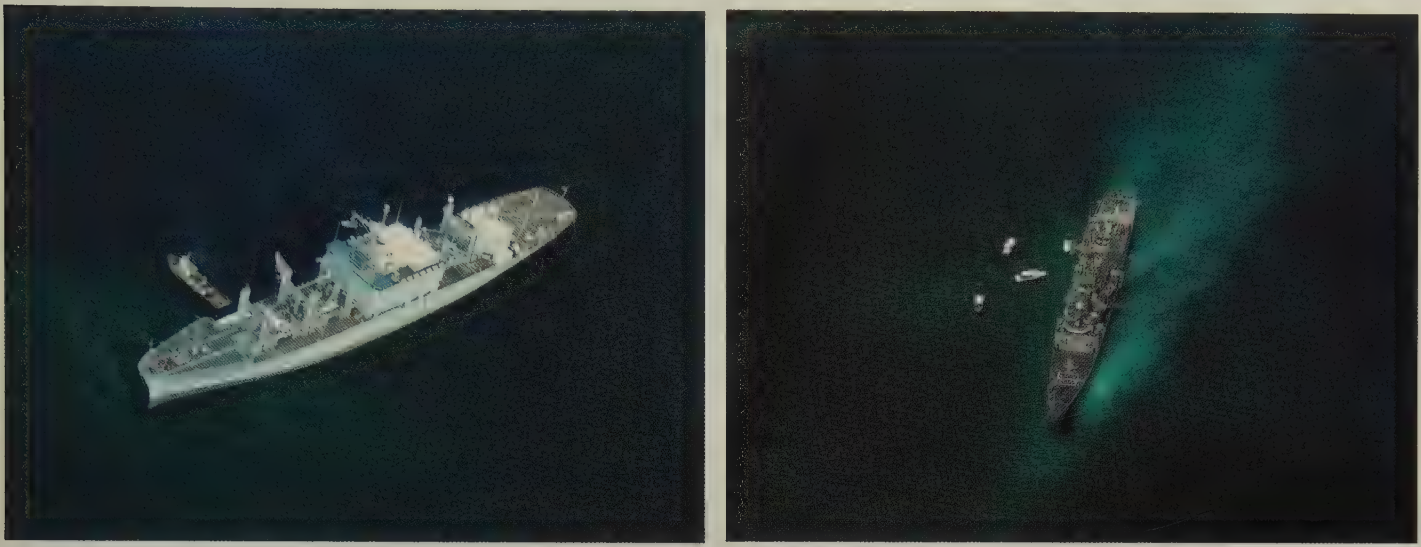


*Figure 16.3. Vessels recently grounded on Palau's reefs include the USNS Niagra Falls (left) and Taiwan Naval Frigate 1103 (right). Photos: CRRF.*

The grounding damaged an area of about 875 m$^2$ of channel edge reef with high cover of coral, particularly table *Acropora* spp. (Colin, 2006). About 350 m$^2$ of reef were crushed and compressed under the hull while an additional 85 m$^2$ had broken reef structure and debris berms which were produced when the ship plowed into the reef. A small down slope movement of debris occurred on the channel slope. The grounding triggered a bleaching event among corals within 10-15 m of the hull covering an area of over 300 m$^2$, probably due to thermal discharges from the ship's generators or engines while grounded. The ship left a large amount of copper-based bottom paint on the site. Virtually 100% of bleached coral colonies, primarily tabulate *Acropora* spp., died following this event. A follow-up study 14 months later (Colin, 2007) found no recovery of the site as a coral reef. Not a single coral recruit occurred in the area of reef crushing, suggesting that the toxins from remaining bottom paint may be inhibiting reestablishment of many organisms. Colin (2007) reexamined the site of a similar grounding in 1997, that of the container ship M/V *Kyowa Violet* (Colin, 1997), and found only minor recovery of that site after almost ten years.

The second major grounding was that of the Taiwanese Naval Frigate 1103 (*Cheng Ho*), a 138 m vessel with a draft of 8.6 m, which struck a reef while entering the main shipping channel (West Channel) of Palau on March 20, 2006 (Figure 16.3). The vessel went aground in 4-5 m of water on the outer slope of the barrier reef as it transited to the channel proper. It remained a ground for two days and was pulled from the site by another Taiwanese naval vessel at high tide.

The vessel grounded in a wave-exposed area where little coral occurs above 6 m depth, so the ship caused minimal damage to reefs. It is estimated less than 50 coral colonies of any size were damaged by the grounding. The reef structure is very solid and no crushing of reef framework occurred. The single, variable pitch propeller of the vessel continued to turn after the ship's bow hit the reef and dug a 1.5 wide by 0.5 m deep groove 20 m in length through the reef limestone as the stern slewed towards the reef. Its blades were finally ripped from the hub and the hub's lubricating oil was released. This quickly dissipated to sea on the outgoing tide. No other discharges occurred from the ship.

A follow up examination of the site six months later found minimal damage to the reef. After the benthic algal film reestablished itself, the site was very difficult even to identify underwater. Some of a limited number of corals damaged could still be easily identified, but overall the site was not significantly affected.

The third major grounding was that of a long-liner fishing vessel (Figure 16.4); the grounding occurred on September 23, 2006. Although this was the first major grounding of a long-liner fishing vessel recorded in this area, the size of the vessel was not recorded. The location of the grounding is at 07°15.896 N, and 134° 3.018 E on the Uchelbeluu Barrier Reef. The ship first came into contact with the reef on the fore-reef area at about 5 m depths. During the grounding, there were strong waves that may have pushed the vessel over the reef crest. Since the strong waves continued for sometime, it further pushed the vessel to the back reef on the lagoon side where it sat exposed during low tide (PICRC, 2006)

On November 10, 2006, the Palau International Coral Reef Center Research (PICRC) staff conducted a rapid assessment of the grounding site. No assessment had been done to describe reef condition before the grounding. As a result, post-grounding results collected over one month after the ship ran aground are the only available data on this reef. Using the line intercept method, coral cover at 3 m depth at the grounding site was determined to be at 34.1 %. The dominant coral species was encrusting *Montipora* (12.1%), followed by *Acropora* (10.8%). About 54% of the surveyed area was hard carbonate substrate (PICRC, 2006).

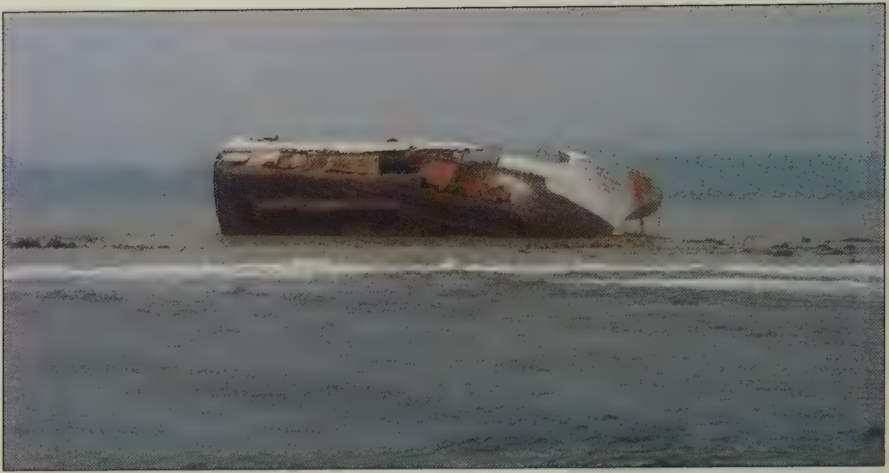


*Figure 16.4. Long liner on its side at Uchelbeluu. Photo: PICRC.*

The impact of the grounding was difficult to determine. While there was some obvious damage to the reef, which may have occurred as a result of vessel removal, based on the assessment and observations made by PICRC staff, it appeared that the ship grounding caused little damage to live coral. The major damage caused by the ship was to the reef structure, particularly on the reef crest and the back reef. Broken corals that were still attached to the reef have shown signs of recovery. Dislodged colonies that had not died will eventually succumb if they are not stabilized (PICRC, 2006).

Toward the end of December 2006, the last grounding included in this report occurred on the southeastern part of Helen Reef, the southernmost part of Palau (Figure 16.5). The grounded vessel was a fishing boat owned by one of the long-line fishing companies operated in Palau. The position of the grounding was 2°49.16N, 131°46.89E.

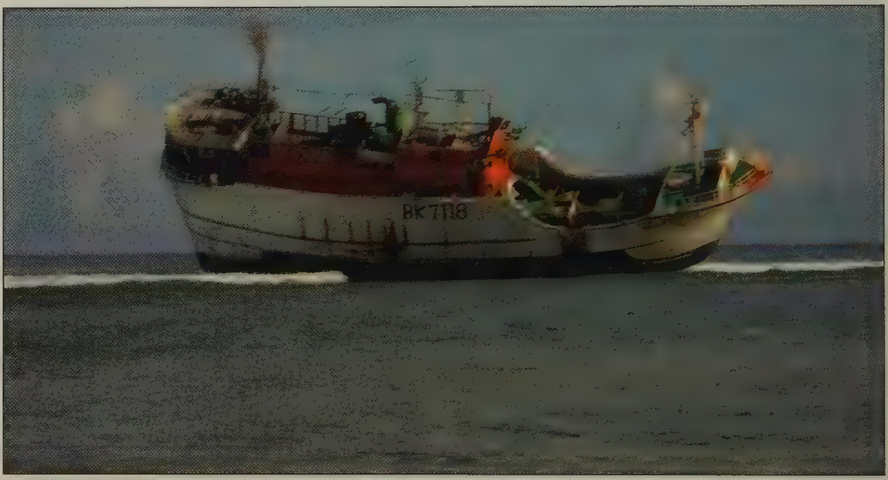


*Figure 16.5. Long liner at Helen Reef. Photo: Helen Reef Resource Management Program.*

The size of the vessel was not stated, but some information on the extent of the damage caused by the grounding was reported. The inner reef structure at the grounding site is very solid with little coral growth. Therefore coral damage on the reef flat was minimal. However, there was visible damage to benthic habitats from the anchor and propeller. The extent of damage on the outer reef area was not assessed due to the presence of big waves and rough water. A few hours after the grounding occurred, the boat caught on fire. Approximately 70-80% of the vessel was destroyed by this fire. There was no obvious sign of an oil spill from the vessel. The Hatohobei State Rangers retrieved a large bundle of tangled up fishing line on the reef flat near where the vessel ran aground. It is believed that this line was thrown overboard by the crew in an attempt to lighten the vessel so that it could be floated off of the reef.

## Marine Debris

Marine debris is common in Palau. It can be found on the beaches around the country. EQPB annually organizes an Earth Day Program which includes a debris removal activity by volunteers who collect trash from both the shores and the water. Koror State also has been active in organizing and implementing Rock Island beach cleanups. Since Palau is a country that relies heavily on importation of goods from neighboring countries, it is hard to determine if debris originated locally or from outside of Palau.

Debris in the form of fishing lines and fishing nets are also commonly sighted in Palauan waters (Figure 16.6). In April 2005, gill nets belonging to an unlicensed fishing boat were reported tangled at 10-20 m depth on the reef edge in Hatohobei Island. Fortunately, the patrol boat from Marine Law Enforcement was in the area and was able to remove the gill nets. The four gill nets recovered contained five turtles that had been caught in the net. Fortunately, damage to the surrounding coral reef was minimal (Tervet, 2005).

In late December 2006 at Helen Reef, a bundle of fishing line was retrieved by state rangers from the reef flat after the rangers rescued the crew from a grounded vessel. Since currents in the area were moving swiftly towards the outer reef edge, some of the fishing lines may have been washed out to sea by the current.

## Aquatic Invasive Species

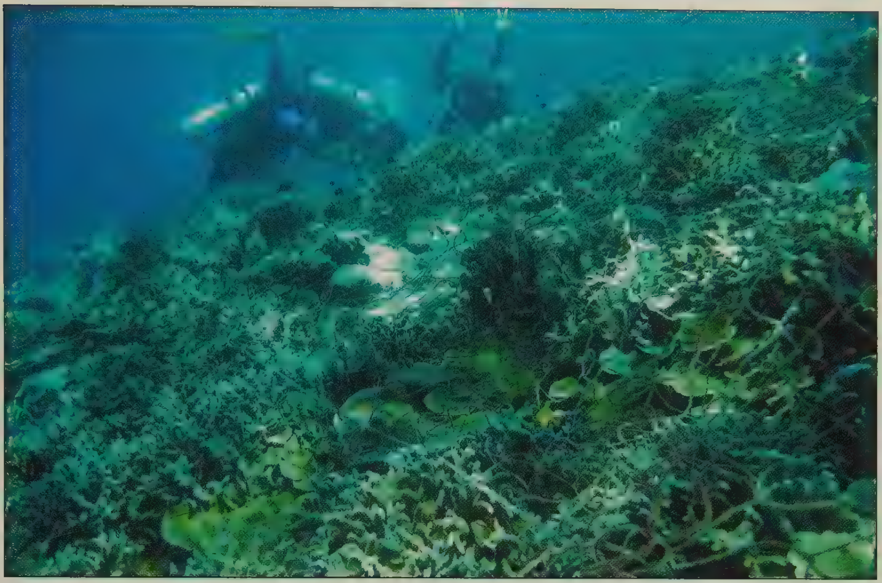


Figure 16.6. Fishing net on the reef. Photo: Marine Law Enforcement.

In July 2007, the National Invasive Species Committee (NISC) hosted a week-long training on detection and response to invasive species in Palau's marine environment. Participants represented national and state government agencies, marine protected areas, non-governmental organizations (NGOs), and the private sector. The participants developed recommendations to enable Palau to respond to the threat of marine invasives. These recommendations have been taken up by the NISC.

The week was devoted to training in survey design and methodology for Palau's Marine Invasives Survey Team, and included hands-on surveying in the field, as well as training in laboratory techniques for sorting and identifying marine invasives. High-risk sites in Malakal Harbor were selected for the training. As a result of this training we now have a 17-member team of divers and support personnel representing national government agencies, state governments, non-governmental agencies, and dive tour companies.

The training was conducted by two experts from Australia, Dr. Chad Hewitt and Dr. Marnie Campbell. It is a priority project of the NISC, with funding from the Republic of China-Taiwan under Operation Counter-Invasion. Additional support was provided by the World Conservation Union, International Union for the Conservation of Nature and Natural Resources, the Marine Bio-security Education Consortium and the Australian Maritime College. In-kind support was provided by local NGO's, state and national government agencies and the private sector.

This workshop and training survey are Palau's first steps to gather baseline information on marine invasive species, and to develop policies and procedures to prevent and control them. It comes as the result of nearly two years of efforts by the NISC to start addressing invasive species in the marine environment, often forgotten compared to their terrestrial counterparts. A report on the findings of the survey and training will be produced before the end of 2007, and will be shared with participants as well as with the public.

Although a comprehensive survey has not been conducted for marine/aquatic invasive species in Palau, several marine invasive species have been identified here (P. Colin, pers. obs.). At present it appears that none of these species are having a quantifiable effect on fisheries or the marine tourism industry, but marine invasive species do have the potential to become a serious problem in Palau, as they have in other Pacific Islands. NISC considers a complete baseline survey of Palau's ports and other high-risk areas a high priority need and is actively seeking funding to complete this survey.

Most marine invasive species in Palau come from a small group of marine invertebrates probably introduced as fouling on ship's hulls or from ballast water pumped out in harbors. Relatively little baseline information exists describing marine invertebrates that are invasive species in Palau. Major groups include ascidians or tunicates (Phylum Chordata, Subphylum Urochordata); hydroids and other cnidarians (Phylum Cnidaria); molluscs (Phylum Mollusca); sponges (Phylum Porifera); bryozoans (Phylum Ectoprocta); and other small groups (P. Colin, pers. obs.).

Given Palau's reliance on imports, there is always the potential for more introductions of marine organisms from ships. For this reason, approaches for controlling marine invasive species should focus on the prevention of introduction and early detection.

Presently only one marine invasive species has the potential for becoming a "pest" organism in Palau, and this is the hydroid, *Eudendrium carneum*. This particular hydroid is a rapidly growing species, which has been found growing in at least three channels of Palau. *E. carneum* prefers rocky substrates with particularly high currents, and often forms a tangle of branches that tend to accumulate sediment, making it a fairly unattractive "weed". As with any marine invasive species, *E. carneum* has the potential to spread throughout rocky marine environments of Palau. *E. carneum* could potentially interfere with the feeding of bottom grazers, such as parrotfishes and surgeonfishes, which scrape algae from rock surfaces. In addition, masses of *E. carneum* tend to make rocky surfaces on the reef less visible and the reef look dirty. At present, the current knowledge on the status and distribution of *E. carneum* in Palau is very limited. It would be useful to survey the extent of its distribution at regular intervals.

### *Invasive Species of Palau's Marine Lakes*

As of 2006, there are three known non-indigenous, invasive species in Ongeim'l Tketau (OTM), also known as Jellyfish Lake: a sea anemone in the genus *Aiptasia*, its symbiotic strain of zooxanthellae, and a sponge belonging to the genus *Haliclona*. It is uncertain where the *Aiptasia* sp., its zooxanthellae (clade E) and the *Haliclona* sp. originated.

### *The Sea Anemone* Aiptasia *sp.*

Relatively small patches of *Aiptasia* sp. were first observed in November 2003 at the foot of the dock where visitors enter the lake. Since then, annual surveys have documented the progress of the invasion eastward along both the north and south shorelines (Figure 16.7). Metrics such as patch area, degree of continuity and density decrease with increasing distance from the original site of introduction. The invasion appears to proceed in a somewhat saltatory fashion with new clusters appearing at points many linear meters ahead of areas of nearly continuous coverage (Figure 16.7). These new colonies can grow quickly. One colony more than doubled in number every month for three months. Their ability to reproduce via pedal laceration likely explains its rapid expansion.

In OTM, *Aiptasia* sp. appear able to establish on any sufficiently hard substrate (Figure 16.8), including mud, rock, mussel shells, algal bottoms, dead leaves and tree falls. The lower boundary of their depth distribution appears to be at least partially limited by available substrate. However, other factors, including light availability and oxygen levels may also contribute. Light availability does not seem to strongly influence its distribution at shallow depths despite its symbiont's need for sunlight. Well developed patches can be found in light limited areas. Temperature may be an important factor influencing abundance and distribution and their rate of spread as well. Qualitative evidence suggests that anemones bleach during warmer conditions.

Currently, no quantitative data exist to describe the impact *Aiptasia* sp. is having on the ecosystem. However, it is clear from direct observation that *Aiptasia* sp. is a thriving competitor for space and can heavily alter benthic diversity (Figure 16.9). Mangrove root and shallow water communities that were once dominated (in terms of both space and numbers) by algae or diverse assemblages of invertebrates are now dominated by invasive anemones. Despite previous experimental eradication of isolated patches, measures to counter the invasion have not been established.

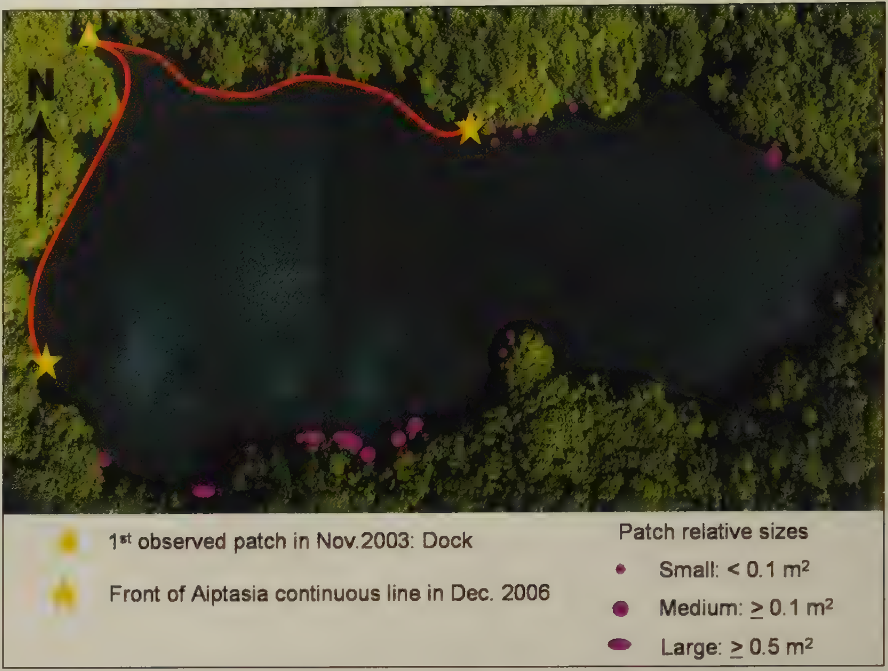

N
1st observed patch in Nov.2003: Dock
Front of Aiptasia continuous line in Dec. 2006
Patch relative sizes
Small: < 0.1 m²
Medium: ≥ 0.1 m²
Large: ≥ 0.5 m²

*Figure 16.7. Aiptasia sp. distribution in Jellyfish Lake in December 2006. Furthest extent of the dense line of* Aiptasia *sp. indicated by orange line and yellow stars. Dots of different sizes represent isolated patches found outside of the continuous dense line. Photo: Coral Reef Research Foundation.*

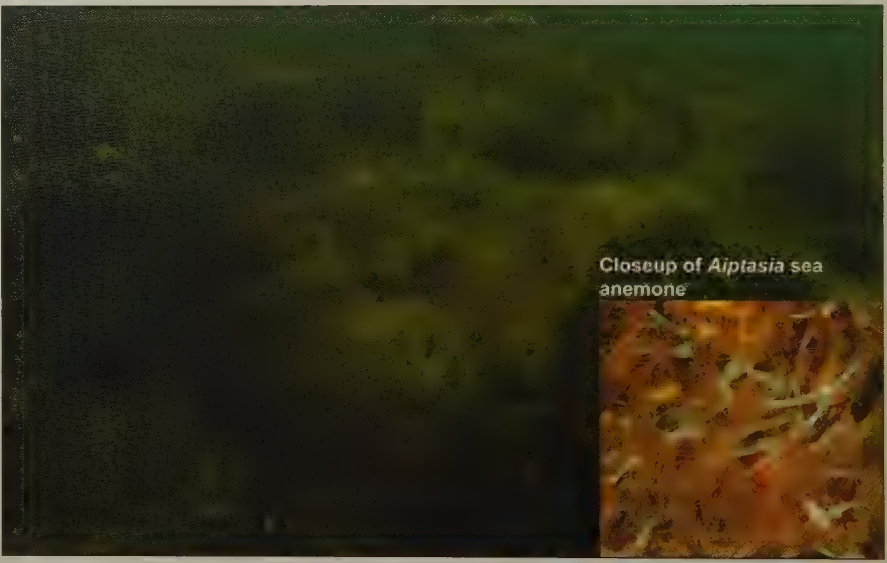


*Figure 16.8. Typical invasive sea anemone patch (mottled brown and white patch among green algae) found along the shallow slope in the west basin of the lake. Inset:* Aiptasia *sea anemone with the characteristic light brown tentacles and white column. Photo: Coral Reef Research Foundation.*

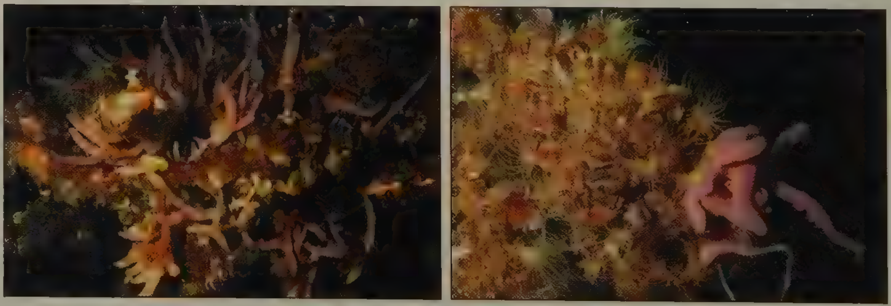


*Figure 16.9. Qualitative impact of* Aiptasia *sp. on benthic diversity. Uncolonized tree fall (left). Community composed of diverse invertebrates, dominated by sponges and mussels. Colonized tree fall (right). One species of sponge and mussel can be seen among the dense cover of* Aiptasia *sp. Photos: Coral Reef Research Foundation.*

### *Clade E Symbiodinium Zooxanthellae*

DNA testing conducted in 2006 indicated that the invasive sea anemone harbors a clade of zooxanthellae (clade E *Symbiodinium*) that differs from the clade of zooxanthellae that is symbiotic with the lake's *Mastigias medusae* (clade C *Symbiodinium*). Thus, it is very likely that the symbiont was introduced into the lake in partnership with the sea anemone and constitutes a second invasive species. As with its anemone host, it is unclear what impact, if any, the introduced *Symbiodinium* will have beyond enabling sea anemone proliferation. However, because *Mastigias* also harbor zooxanthellae, it is possible that the non-native *Symbiodinium* could become established in *Mastigias*. It is not possible at this time to predict what effect, if any, such an event might have on the jellyfish's ecology but temperature and light tolerances do differ among *Symbiodinium* clades.

### *The Sponge* Haliclona *sp.*

Although *Haliclona* sp. (Chalinidae, Haplosclerida) was first recognized as a non-indigenous species in OTM in June 2005, photographic evidence indicates that it was present in 2001. Due to striking similarities in color and morphology, *Haliclona* sp. can easily be mistaken for the lake's native *Dragmatella* sp. (Desmacellidae, Poecilosclerida). Consequently, its status as a non-native in OTM only became apparent after a broader survey of invertebrate diversity was conducted in 13 of Palau's marine lakes.

The sponge's exact identification (to species level) and its origin are still unknown, but it appears to characteristically and exclusively inhabit well connected marine lakes, which are environmentally very similar to the lagoon where the species also appears to occur naturally. Its status as a non-native in OTM is also supported by its spatial distribution, which is currently restricted to the extreme western edge of the lake near the dock and through the entrance channel where visitors enter the lake. Here several large patches, much larger than those formed by any native species, occur between 0.5 and 6 m depth along the northern side of the entrance channel. The effect this species is having and will have on the lake is unknown Figure 16.10.

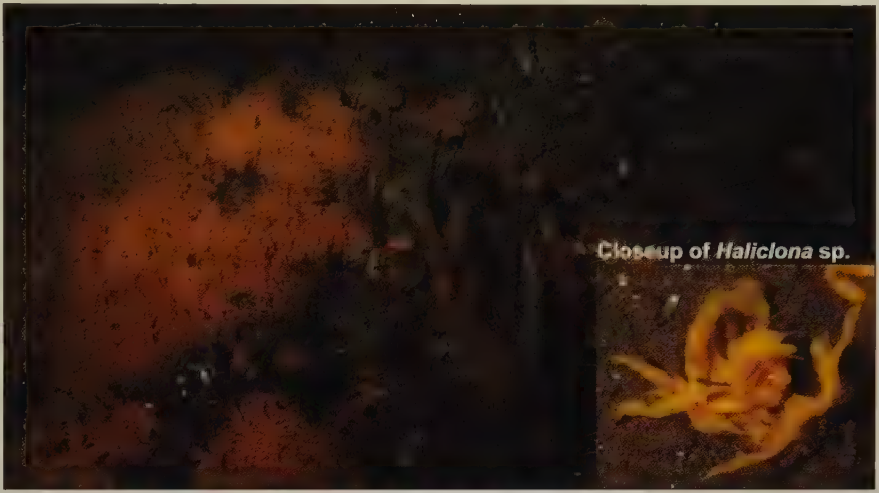


*Figure 16.10. Non-native* Haliclona *sp. colony near the dock from which tourists enter the lake. Inset: Non-native* Haliclona *sp. is easily mistaken for the native* Dragmatella *sp. Photo: Coral Reef Research Foundation.*

## Security Training Activities

Since the last report, security training activities continued to be non-existent in Palau.

## Offshore Oil and Gas Exploration

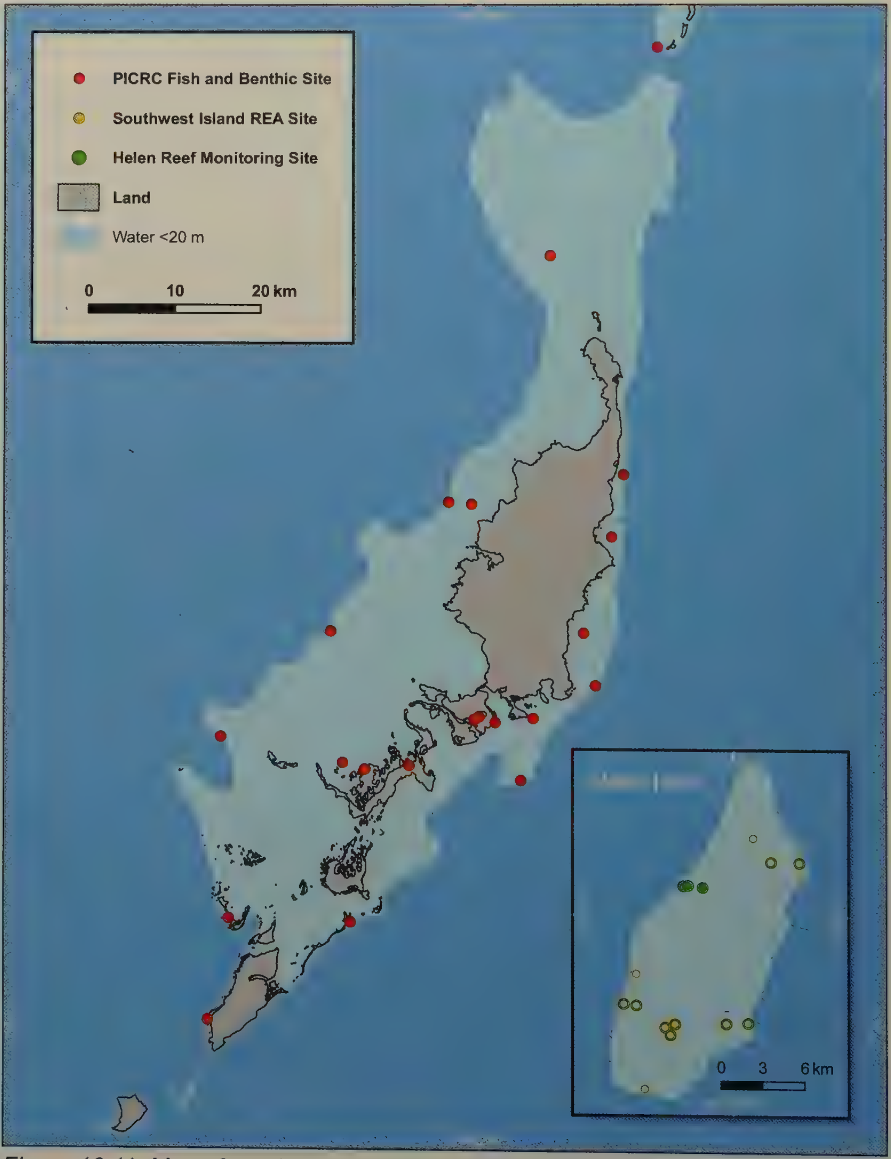
Since the last report, there has not been any oil extraction in and around Palau. However, in the past four years, oil exploration has been carried out in the northern Velasco Reef. On the southern end of Velasco Reef is a conservation area. An agreement on oil exploration and extraction has been signed by the leaders of Kayangel State that owns the Velasco Reef as well as four other outlying states in the south (Peleliu State, Angaur State, Sonsorol State and Hatohobei State). In 2006, the oil company carried out an environmental assessment (EA) in Velasco Reef as required by the EQPB, which is still under review. To date, this is the only EA that been carried out and submitted for review.

## CORAL REEF ECOSYSTEMS—DATA-GATHERING ACTIVITIES AND RESOURCE CONDITION

A multi-level effort by different government and non-government agencies contributes to the general understanding of coral reef ecosystems and marine life in Palau. Table 16.7 provides a general understanding of the effort undertaken by various agencies and organizations. Figure 16.11 depicts the location of ongoing monitoring activities throughout Palau.

*Table 16.7. Monitoring and assessment activities in Palau.*

| AGENCY | PLANNING/ MANGEMENT | RESEARCH | MONITORING | EDUCATION /OUTREACH | TRAINING | ENFORCE-MENT | YEAR EST. |
|---|---|---|---|---|---|---|---|
| Bureau of Natural Resources and Development | X | X | Ngermeduu Bay, Clam export and fish market | | X | X | 1990 |
| Coral Reef Research Foundation | | X | Temperature, marine lake | | | | 1998 |
| Environmental Quality Protection Board | | | Water quality | X | | X | 1992 |
| Helen Reef Resource Management Board | X | | MPA | X | X | X | 2000 |
| Koror State Department of Conservation and Law Enforcement | X | X | Marine lakes, Rock Island, MPA | | | | 1994 |
| Palau Conservation Society | X | | MPA's | X | X | | 1996 |
| Palau International Coral Reef Center | | X | Fish, coral MPA's, watersheds | | | | 2001 |
| The Nature Conservancy | X | X | MPA Network | X | X | | 2003 |



● PICRC Fish and Benthic Site
● Southwest Island REA Site
● Helen Reef Monitoring Site
▨ Land
Water <20 m
0
10
20 km
0
3
6 km

*Figure 16.11. Map of monitoring locations in Palau. Map: K. Buja.*

## WATER QUALITY AND OCEANOGRAPHIC CONDITIONS

The Environmental Quality Protection Board of Palau (EQPB) conducts monthly water quality monitoring of marine waters around most of Palau. Turbidity, pH, salinity, dissolved oxygen, fecal coliform and temperature are collected monthly at 40 permanent sites (Figure 16.12). Sampling sites were selected because they are either a popular recreational site or in close proximity to a sewage substation. Results from the monitoring program are added to a database that dates back to 1992. Figure 16.12 shows the average monthly values for each parameter tested, with the exception of the month of April. In 2006, fecal coliform bacteria averages throughout the nearshore marine waters in Palau were well below the safe recreational water standards set for by the EQPB. In addition, turbidity, pH, temperature, dissolved oxygen and salinity levels were within the set standards.

EQPB issues an "unsafe for swimming" warning when the fecal coliform count at a site exceeds 200 bacteria per 100 mL. For the most part, the 40 sites sampled monthly have had fecal coliform counts less than this threshold. However, in February, June and December of 2006, at least a quarter of monitoring sites had fecal coliform counts near 200 bacteria per 100 mL.

Figure 16.13 shows the monthly averages in 2006 for turbidity levels, which is measured in nephelometric turbidity units (NTU). The highest averages were in the month of July, which corresponds with the rainy season. Average monthly pH levels ranged from 7.9 to 8.4, which fall within the marine water quality standards for Palau. In 2006, the average turbidity was below 2 NTU, except in May and July when it exceeded 2 NTU (Figure 16.13). The increase in turbidity in May and July could be the result of increased earth moving activities or more rain during those months.

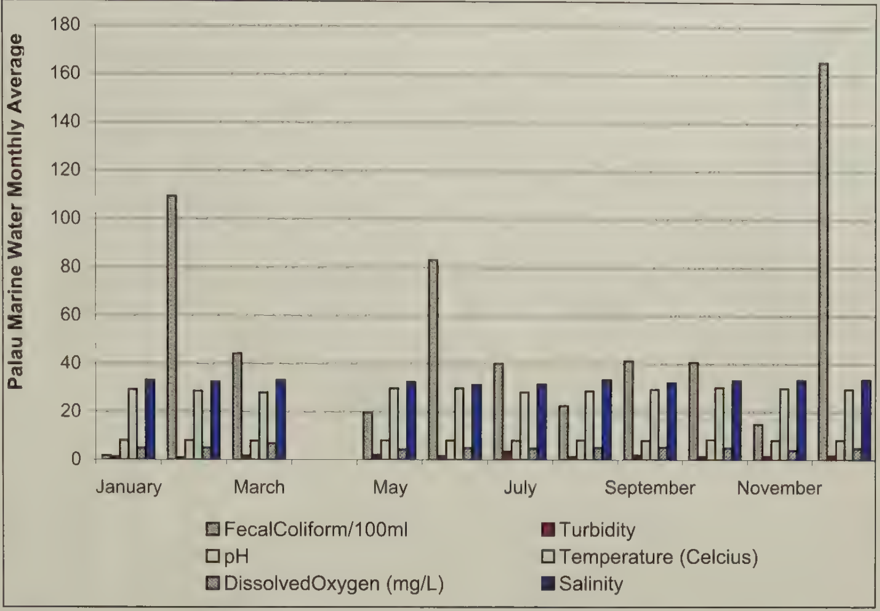


*Figure 16.12. Comprehensive water quality graph for Palau in 2006. Source: EQPB.*

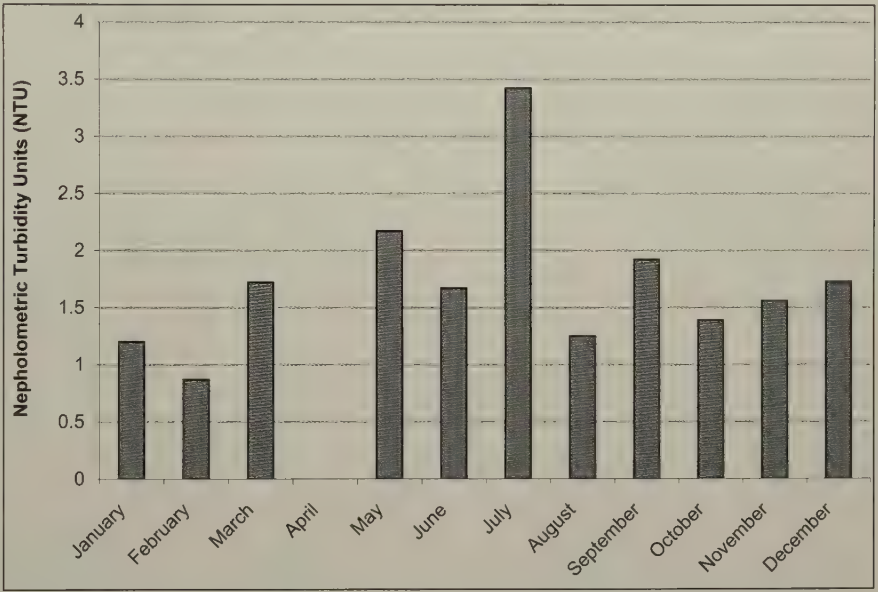


*Figure 16.13. Average turbidity levels in Palau water in 2006. Source: EQPB.*

No major shifts in average monthly temperature were recorded for 2006. Dissolved oxygen levels were just within the lowest acceptable limits for Palau. Temperature, pH and dissolved oxygen are shown in Figure 16.14. Average salinity levels in June and July show rainy season impacts. Table 16.8 summarizes the water quality data for 2006.

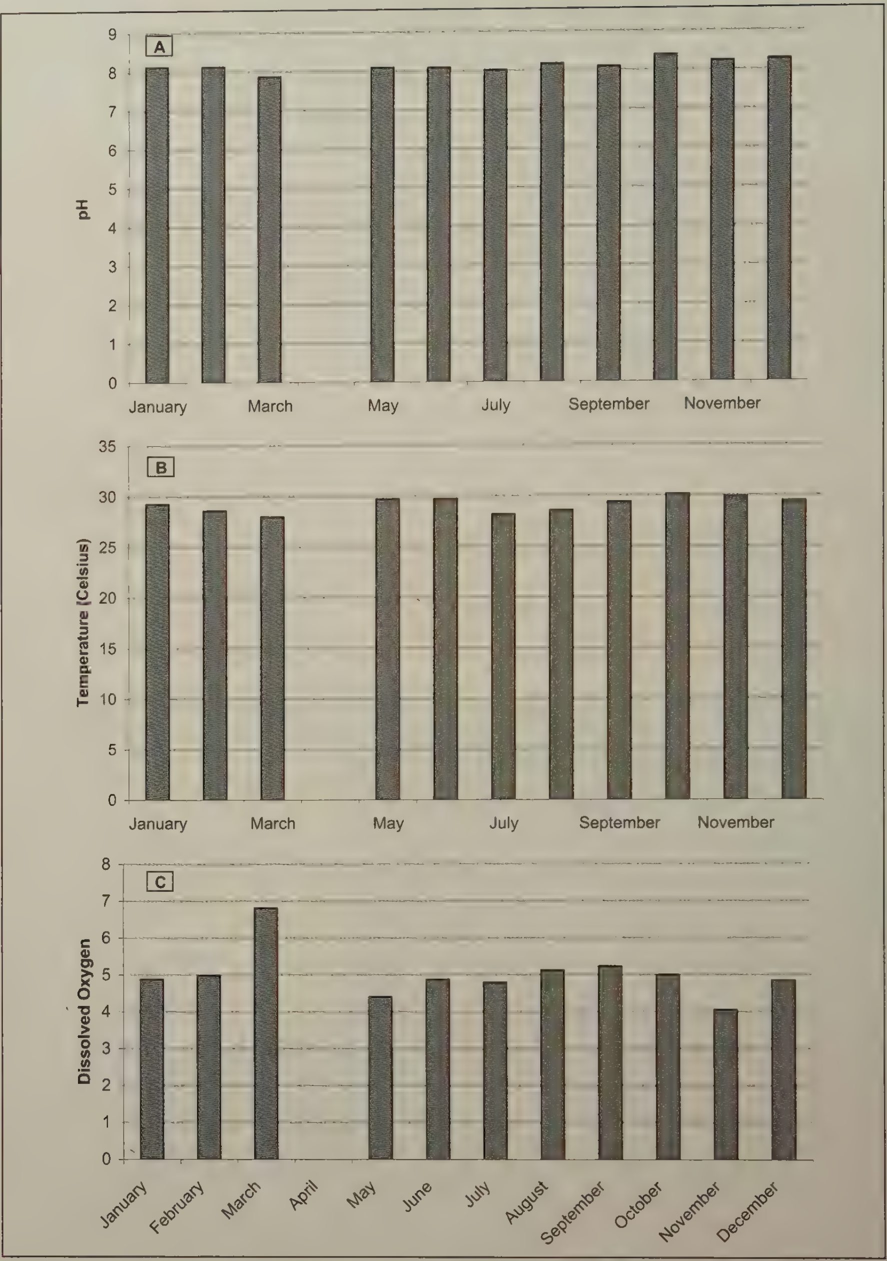


*Figure 16.14. (a) Average pH levels in Palau waters in 2006; (b) Average temperature (˚C) levels in Palau water in 2006; (c) Average dissolved oxygen (mg/L) levels in Palau water in 2006. Source: EQPB.*

*Table 16.8. Monthly averages of 2006 water quality data for various parameters. Source: EQPB.*

| MONTH | FECALCOLIFORM (per 100 ml) | TURBIDITY | PH | TEMPERATURE (˚C) | DISSOLVED OXYGEN (mg/l) | SALINITY |
|---|---|---|---|---|---|---|
| January | 1.75 | 1.2 | 8.13 | 29.27 | 4.88 | 33.15 |
| February | 109.5 | 0.87 | 8.13 | 28.59 | 4.98 | 32.46 |
| March | 44.1 | 1.72 | 7.87 | 27.97 | 6.81 | 33.2 |
| April | 0 | 0 | 0 | 0 | 0 | 0 |
| May | 19.65 | 2.17 | 8.09 | 29.71 | 4.4 | 32.32 |
| June | 83.08 | 1.67 | 8.08 | 29.69 | 4.87 | 31.24 |
| July | 40 | 3.42 | 8.01 | 28.17 | 4.79 | 31.43 |
| August | 22.57 | 1.25 | 8.17 | 28.57 | 5.12 | 33.34 |
| September | 41.21 | 1.92 | 8.09 | 29.37 | 5.23 | 32.14 |
| October | 40.72 | 1.39 | 8.38 | 30.13 | 5 | 33.06 |
| November | 14.93 | 1.56 | 8.23 | 29.87 | 4.05 | 33.28 |
| December | 165.59 | 1.73 | 8.27 | 29.42 | 4.85 | 33.36 |

## BENTHIC HABITATS

Coral Ecosystem monitoring by the PICRC began in 2001 and has continued to the present. It started with the establishment of 14 permanent monitoring sites in 2001. Two more sites were added in 2002 and five were added in 2005. Currently, there are 21 permanent monitoring sites. Video transects are utilized to survey benthic habitats (Golbuu et al., 2005; Golbuu et al., 2007a; Golbuu et al., 2007b) and five 50 x 5 m belt transects are used for fish surveys (Golbuu et al., 2005). Coral recruitment surveys were also conducted using 0.30 x 10 m belt transects (Golbuu et al., 2005; Golbuu et al., 2007a; Golbuu et al, 2007b). Figure 16.15 shows coral cover on reefs around Palau in 2001, 2002 and 2005 at four different habitats.

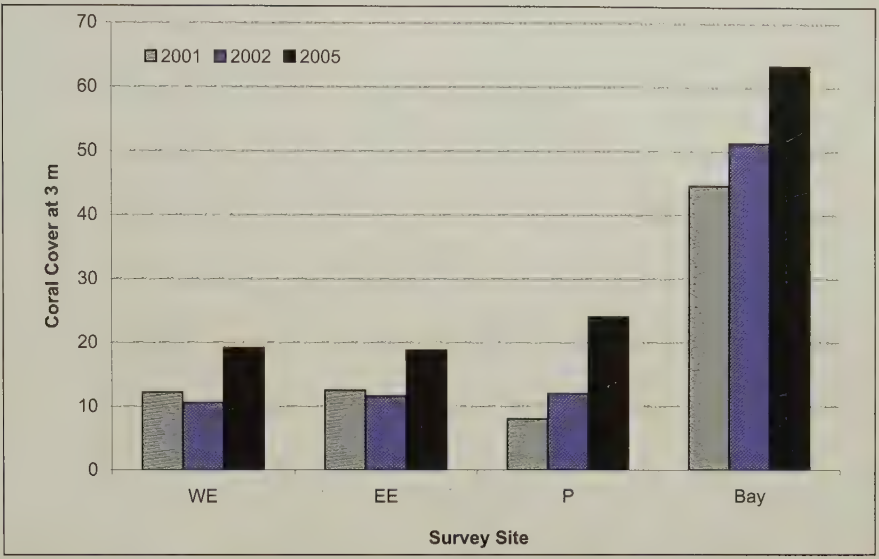


*Figure 16.15. Average coral cover at four habitat types found in Palau at 3 m depth: western exposed reefs (WE), eastern exposed reefs (EE), patch reefs (P) and reefs around the rock islands (Bay). Source: Golbuu et al., 2007b.*

Before the 1998 bleaching event, Palau coral reefs were generally in good condition with high coral cover. After the 1998 bleaching, coral cover was reduced at most sites around Palau (Golbuu et al., 2007a; Table 16.9). The largest reduction in coral cover caused by the bleaching was found at the western slopes of the northern lagoon where coral cover dropped from 60-70% to 15%; coral cover in the Southern Lagoon dropped from 50-70% to 14-23% over the same period (Golbuu et al., 2007).

Table 16.9 shows coral cover at different regions of Palau as recorded by the 1992 Rapid Ecological Assessments (REAs; Maragos et al., 1994), the 2001-2003 Spot Checks, the 2005 surveys of the permanent sites from the PICRC long-term monitoring programs, and other studies.

*Table 16.9. Coral cover at different regions of Palau as recorded by the 1992 Rapid Ecological Assessments (Maragos et al., 1994) the 2001-2003 Spot Checks, the 2004/2005 surveys of the permanent sites from the PICRC long-term monitoring programs, and other studies. Source: Golbuu et al., 2007a.*

| LOCATION | 1992 REA (RANGE) | 2001–2003 SPOT CHECKS (MEAN ± SE) | 2004/2005 SURVEYS (MEAN ± SE) | OTHERS (RANGE) |
|---|---|---|---|---|
| Kayangel | 20 – 25 | 30 ± 4 | 25 ± 3 | |
| Northern Lagoon: Barrier- NE slopes<br>Barrier- W slopes<br>Patch | 10<br>60 – 70<br>N/A | 13 ± 2<br>15 ± 2<br>20 ± 6 | NA<br>NA<br>26 ± 6 | |
| West Babeldaob: Barrier<br>Channels<br>Patch<br>Fringing | N/A<br>50 – 70<br>50<br>33-50 | 23 ± 2<br>14 ± 2<br>20 ± 3<br>33 ± 6 | 28 ± 4<br>NA<br>10 ± 2<br>NA | 17 – 35<br>(*Golbuu, 2000*) |
| East Babeldaob : Barrier<br>Patch<br>Fringing | 50 or more<br>NA<br>10-50 | 14 ± 2<br>NA<br>22 ± 3 | 33 ± 8<br>8 ± 3<br>16 ± 2 | 10 – 30<br>(*PCS, 1999*) |
| Southern Lagoon: Barrier<br>Channels<br>Channel-Ngerumekaol<br>Patch<br>Fringing | 50<br>25 – 50<br>52<br>N/A<br>N/A | 17 ± 2<br>N/A<br>23 ± 5<br>35 ± 5<br>39 ± 5 | 27 ± 2<br>NA<br>NA<br>NA<br>48 ± 3 | 23<br>(*Golbuu et al., 1999*) |

From 2001 to 2005, coral cover on the reefs of Palau generally increased at both 3 and 10 m depths with the highest rate of increase found on Bay reefs (Golbuu et al., 2007b; Figures 16.15 and 16.16). Coral cover at deeper sites (10 m) generally increased 4% more than at shallower sites (3 m; Golbuu et al., 2007a). Overall, the increase in coral cover over this period averaged 2.9% per year (Golbuu et al., 2007a).

Coral recruitment was variable between the years with the highest recruitment rate recorded in 2002 (Golbuu et al., 2007a). Among the different sites, west exposed sites had the highest rate of recruitment at 10 m depth (Figures 16.17). There are no relationships with recruitment and coral cover (Golbuu et al., 2007b)

Generally coral reefs in Palau are recovering well from the 1998 bleaching event. Recovery is dependent on both remnant populations that survived the 1998 bleaching as well as on recruitment (Golbuu et al, 2007b).

### Benthic Habitat Mapping

In November 2007, NOAA's CCMA-BB released benthic habitat maps covering 2,450 km$^2$ (946 mi$^2$) of nearshore marine habitats in Palau (Figure 16.18). Summary data indicate that about 35% of the area mapped contains live coral cover and that significant areas are covered by macroalgae, crustose calcareous algae, and sand. Deep lagoon areas were not able to be mapped since the seafloor was not visible in the IKONOS satellite imagery that was used to develop the maps.

The mapping effort was requested by Palau to support development of local monitoring programs and help resource managers evaluate the effectiveness of Palau's system of marine reserves and help identify areas in which additional (MPAs) can be established. Access to the source imagery and various map products is available at: http://ccma.nos.noaa.gov/products/biogeography/palau/welcome.html.

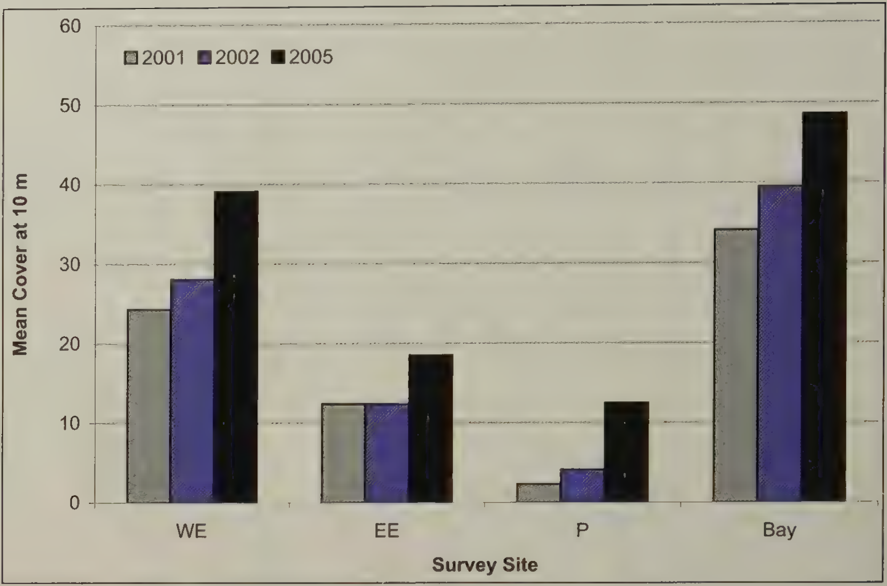


*Figure 16.16. Average coral cover at four habitat types found in Palau at 10 m depth. Western exposed reefs (WE), eastern exposed reefs (EE), patch reefs (P) and reefs around the rock islands (Bay). Source: Golbuu et al., 2007b.*

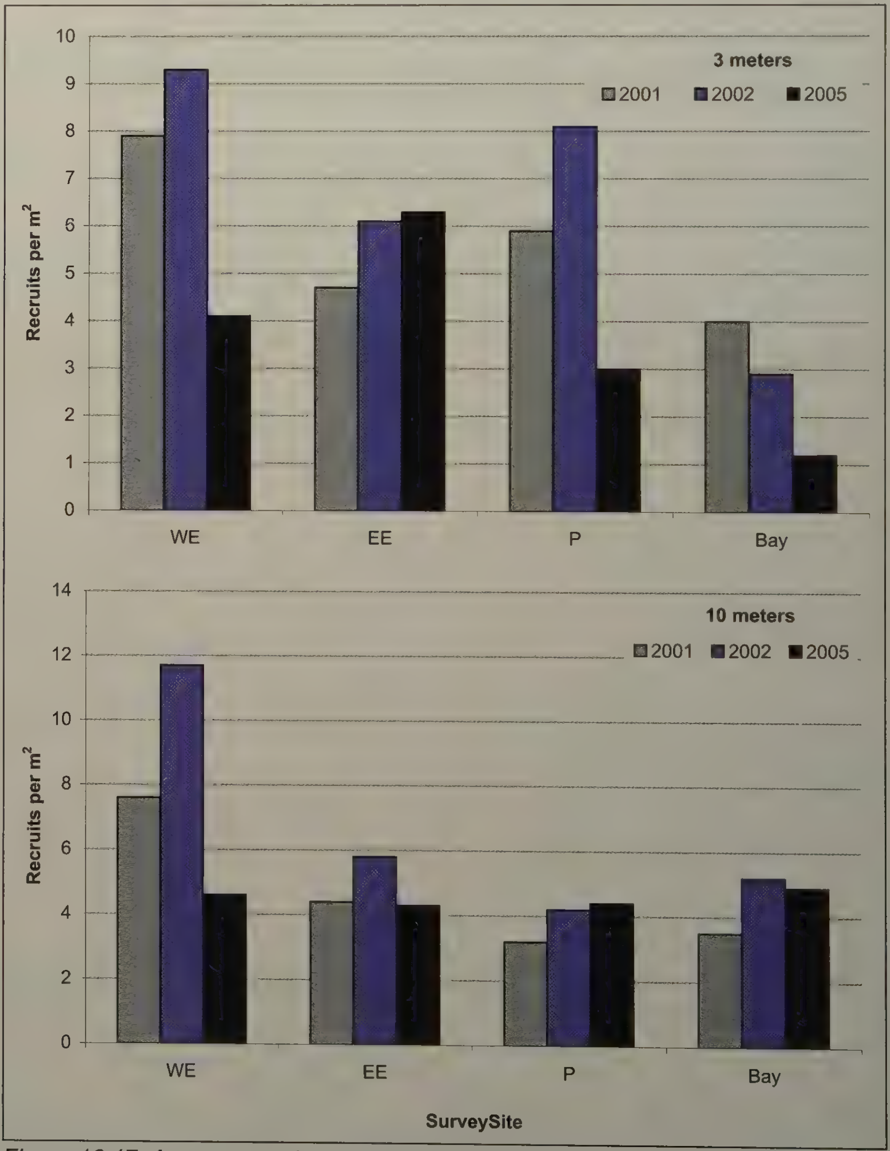


*Figure 16.17. Average coral recruitment by habitat type at 3 m (top) and 10 m (bottom) depth. Source: Golbuu et al., 2007b.*

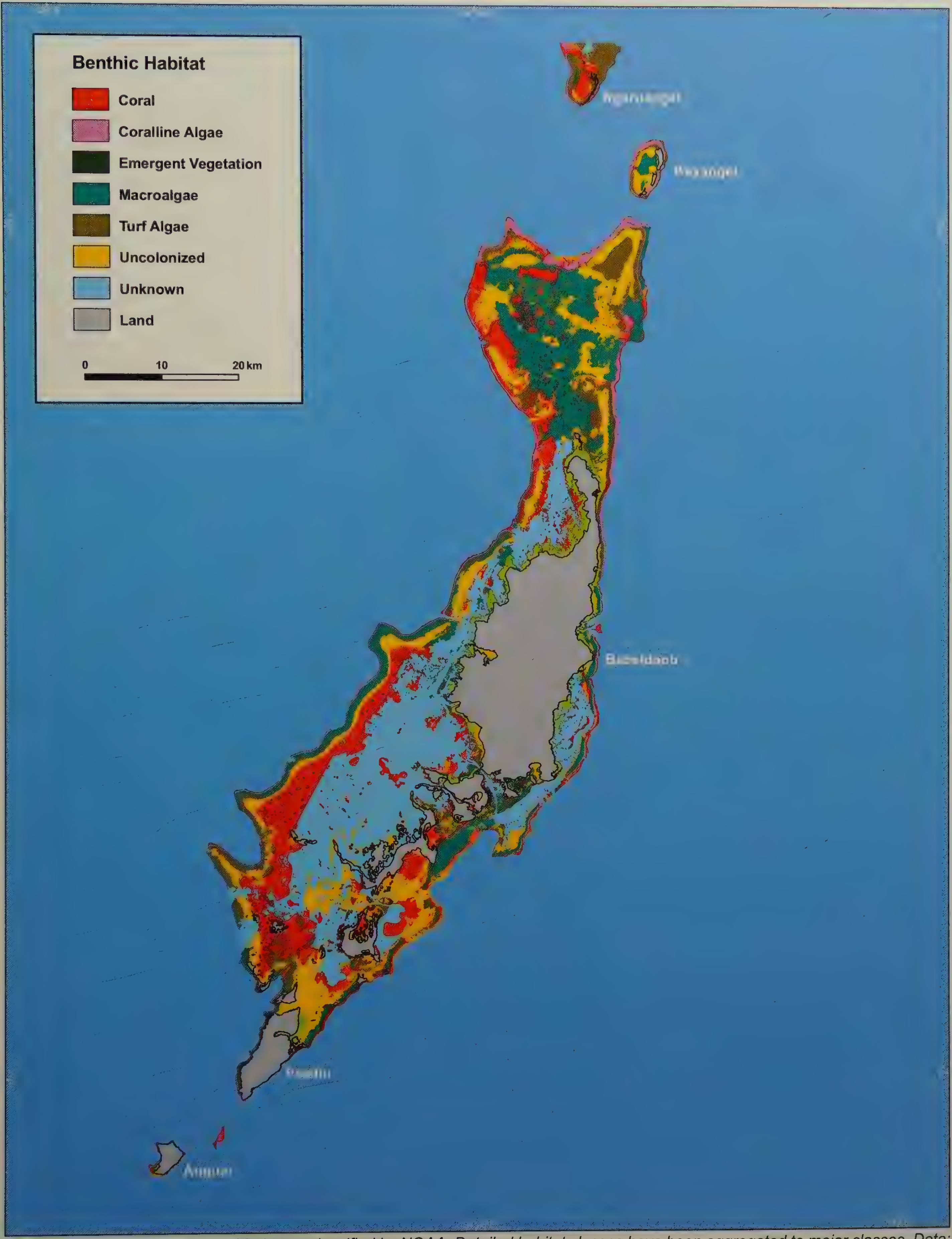

**Benthic Habitat**
🟥 Coral
Coralline Algae
Emergent Vegetation
Macroalgae
Turf Algae
Uncolonized
Unknown
Land
0
10
20 km
Ngaruangel
Kayangel
Babeldaob
Peleliu
Angaur

*Figure 16.18. Benthic habitats of Palau as classified by NOAA. Detailed habitat classes have been aggregated to major classes. Data: http://ccma.nos.noaa.gov/products/biogeography/palau/welcome.html. Map: K. Buja.*

## ASSOCIATED BIOLOGICAL COMMUNITIES

### Fish

Fish surveys were conducted at permanent monitoring sites using visual census techniques on five, 5 x 50m belt transects (Golbuu et al., 2005).

Fish abundance increased in 2004 in all the sites at 3 m and west exposed and patch reef sites at 10 m (Figures 16.19). East exposed sites and bay reefs did not have significant increases in 2005 (Figure 16.19). For the habitats with different exposures, west exposed sites has the highest number of fish, followed by east exposed and path reefs. Bays had the lowest number of fish. Fish abundance at west exposed sites in 2004 were higher at 10 m than at 3 m, while east exposed patch and bay reefs showed a different pattern with higher abundance at shallower water (Figures 16.19).

Despite fishermen's concerns that there is a decrease in fish as a result of their increased fishing effort, fish data shows a general increase in 21 fish species at selected monitoring sites. The data as presented are total fish population of these selected species. There exists an inability to conduct analysis to determine which species are increasing and which ones are decreasing.

The Palau Marine Protection Act of 1994 puts size, exports and seasonal restrictions on certain commercially important reef fish species, such as groupers, rabbit-fish, napoleon wrasse and humphead parrotfish. In 2006, Palau instituted a total ban on the collection of napoleon wrasse until some sort of assessment is done to provide recommendation on the status of this species.

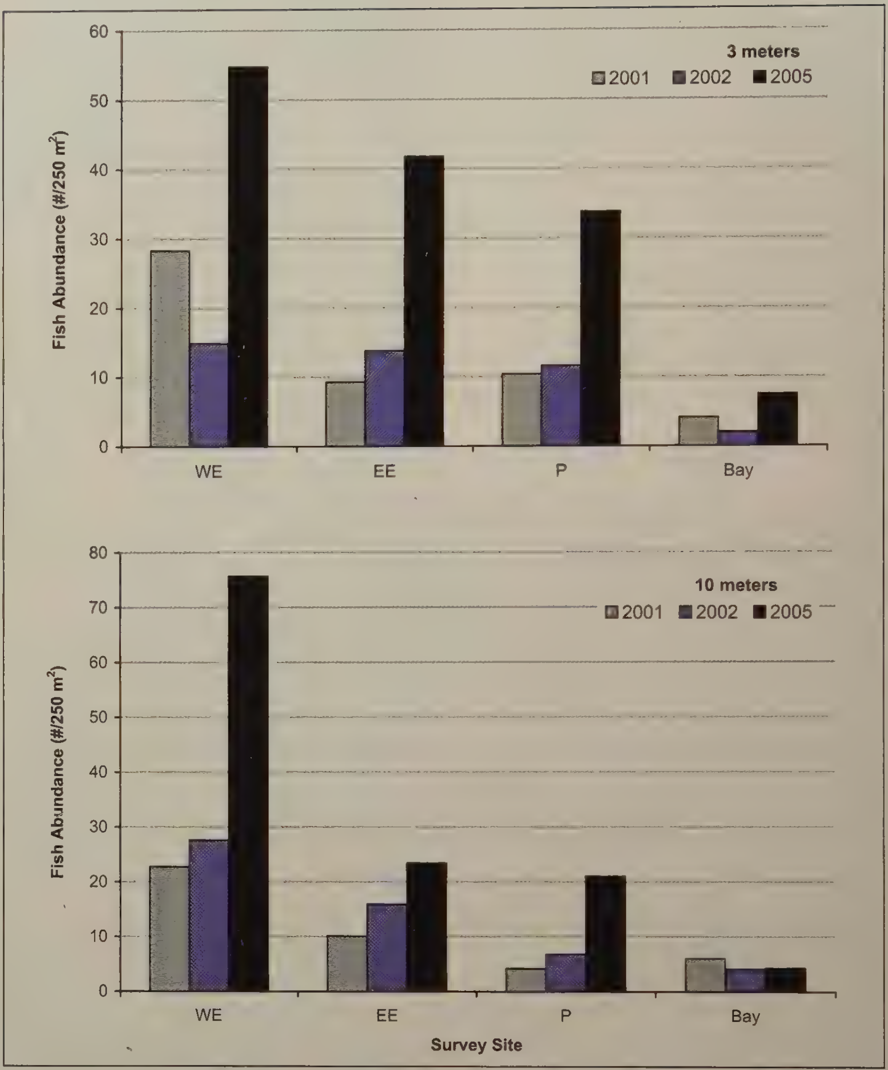


*Figure 16.19. Average fish abundance at five habitat types at 3 m depth (top) and 10 meters (bottom). WE=west exposed; EE=east exposed; P=protected. Source: Golbuu et al., 2007a.*

There is a lack of baseline data to permit the determination of whether there is indeed a decline in fish populations at the species level. However, despite all these management efforts at the policy level and at community level to establish MPA's, fishermen are still concerned over a decrease in fish populations.

### Invertebrates

Invertebrates were only added to monitoring activities in 2007; no data are available for this report, but results will be presented in the next report. There is a general consensus that most commercially important invertebrates on the reefs are declining due to over-harvesting. Despite restricted export under the 1994 Marine Protection Act, giant clams (*Trochus* spp.) have experienced a decline. There is a government effort in providing seedlings to interested individuals to raise clams and there are many clam farm in existence throughout Palau on the inter-tidal reefs flats. There hasn't been any assessment to determine whether there are possible negative environmental impacts on the reefs of these activities.

## CURRENT CONSERVATION MANAGEMENT ACTIVITIES

The Palau Ministry of Resources and Development (MRD) has overlapping jurisdiction with each of Palau's 16 state governments for all marine areas within 12 nm of the high tide watermark. Various governmental and NGOs have conducted research and monitoring projects to aid in the management of Palau's coral reef ecosystems. National and state agencies, in coordination with locally based NGOs, have put a variety of management tools in place to address issues such as fishing, recreational use, and land-based sources of pollution in order to protect the marine resources of Palau.

## Marine Protected Areas

MPAs have been established throughout Palau by states and local communities to provide protection for marine resources (Table 16.10). Several more of these protected areas have been designated over the years, thereby providing

*Table 16.10. Marine Protected Areas of Palau. Source: PICRC and PCS.*

| MPA | YEAR | PROTECTED HABITATS | AUTHORITY | RESTRICTIONS |
|---|---|---|---|---|
| Ngerukuid Preserve | 1956<br>1999 | Lagoon, patch reef, limestone islands | National Government, Koror State Government | No entry |
| Ngerumekaol Spawning Area | 1976<br>1999 | Reef channels, barrier reef, lagoons | National Government, Koror State Government | No fishing |
| Ngaraard Beach Conservation Area | 1990 | Patch reefs, lagoon, beach, seagrass beds | Ngaraard State Government | No fishing |
| Airai Mangrove Conservation Area | 1994 | Mangrove, fringing reef | Airai State Government | Subsistence fishing and educational uses only |
| Ngaraard Mangrove Conservation Area | 1994 | Mangrove, fringing reef | Ngaraard State Government | Subsistence fishing and educational uses only |
| Ngemelis Island Complex | 1995<br>1999 | Lagoon, patch reefs, barrier reef, limestone islands | Koror State government | No fishing; no operation of motor boat between island complex |
| Ngeruangel Preserve | 1996 | Atoll, patch reefs, lagoon | Kayangel State Government | No entry without permit |
| Ngeream Conservation Area | 1997 | Limestone island, mangrove, fringing reef | Airai State Government | Subsistence fishing and educational uses only |
| Melekeok Management Area | 1997 | Fringing reef | Melekeok State Government | No net fishing |
| Ngkisaol Sardine Sanctuary | 1999 | Mangrove, patch and fringing reefs | Koror State Government | No take |
| Ebiil Conservation Area | 2000 | Channel, patch reefs, lagoons, barrier reef | Ngarchelong State Government | No entry |
| Ngermeduu Bay | 2000 | Mangroves, mudflats, seagrass beds, fringing reefs, reef channel | National Government, Aimeliik, Ngatpang and Ngaremlengui State Governments | Subsistence fishing and educational uses only |
| Helen Reef Reserve | 2001 | Atoll, patch reefs, lagoon, channel | Hatohobei State Government | No entry |
| Ngederrak Reef Area | 2001<br>2005 | Seagrass beds, lagoon | Koror State Government | No entry for motorized watercraft |
| Teluleu Seagrass Conservation Area | 2001 | Seagrass bed | Peleliu State Government | No entry |
| Ngelukes Conservation Area | 2002 | Patch reef, seagrass beds | Ngchesar State Government | No entry |
| Ngerkebesang Conservation Zone | 2002 | Beach, fringing reef | Koror State Government | No take |
| Imul Mangrove Conservation Area | 2002 | Mangrove, fringing reef | Aimeliik State Government | No take |
| Ngchesechang Mangrove Conservation Area | 2002 | Mangrove, fringing reef, reef channel | Airai State Government | Subsistence fishing and educational uses only |
| Ngermasech Reef Conservation Area | 2003 | Seagrass beds, fringing reefs | Ngardmau State government | No entry |
| Ngatpang Fish Conservation Area | 2004 | Mangrove, fringing reef | Ngatpang State Government | No entry |
| Ngatpang Clam Conservation Area | 2004 | Patch reef | Ngatpang State Government | No entry |
| Ngatpang Crab Conservation Area | 2004 | Mangrove | Ngatpang State Government | No entry |
| Ileaklbeluu Conservation Area | 2005 | Patch reef | Ngardmau State Government | No entry |
| Angaur State Conservation Zone | 2005 | Fringing reef | Angaur State Government | No fishing, except on reef slope (spear fishing only) |
| Medal a Ngerang Management Area (Ngerang Clam Farm) | 1999 | Seagrass bed, fringing reef | Melekeok State Government | No clam harvest |
| Airai Reef Conservation Area | 2005 | Mangrove, fringing reef | Airai State Government | No entry |
| Ngerchebal Island Wildlife Conservation Area | 2006 | Volcanic island, patch reefs | Aimeliik State Government | No entry |
| Oikull Mangrove Conservation Area | 2002 | Mangrove, channel | Airai State Government | Subsistence and educational uses only |
| Bkulengriil Conservation Area | 2006 | Fringing reef, seagrass bed, mangrove | Ngaremlengui State Government | No fishing |

protection for a greater percentage of coral reef ecosystems. In 2007, there were 31 MPAs, covering more than 40% of Palau's nearshore marine area.

Most of Palau's MPAs have been designated by the states and management of these areas falls under the authority of the local governments. In addition, there are MPAs designated by the national government for the purpose of protecting biodiversity and significant habitats. The designation of a MPA by the local governments is initiated by the implementation of a traditional moratorium, or 'bul', on the area, prohibiting all use for a restricted time period (usually one to three years). The majority of these MPAs were designated to address local concerns related to decreased commercial reef fish populations. The Palau Conservation Society (PCS) and TNC have been working in partnership with state governments to implement community-level monitoring and management programs within the MPAs and to produce management plans that will take effect after the moratorium period has expired. In the last several years, more of these MPAs have also been designated through legislation by the state governments to provide a legal basis for management action.

### Helen Reef Management Area

Helen Reef is a large, biologically-significant atoll located in the remote Southwest Islands of Palau with a reef size of 163 km². It is the traditional fishing ground for the Hatohobei people who have depended on Helen Reef as an important source of food for many generations. In recent decades, foreign poaching and overfishing have threatened the biological health of the Reef.

In response to these challenges, the people and the state of Hatohobei made attempts to protect and better manage Helen Reef's resources, including the formation of the Helen Reef Resource Management Program and the enactment of state legislation declaring the area a marine reserve and protected area. Since the inception of the Program in 1999, community members from Hatohobei State have been successful in protecting the reef from outside poachers and overfishing. A community monitoring, surveillance and enforcement program has been implemented since 2002 and a new management plan has recently been developed to address ongoing management and project sustainability (Andrew, 2007). Tables 16.11 and 16.12 provide more information about the locations and objectives of monitoring work at Helen Reef.

*Table 16.11. Location of study sites and objectives for quantitative survey design combined for fishes, corals and macroinvertebrates. Source: Helen Reef Project.*

| LOCATION | SITE # | GENERAL DESCRIPTION | STANDARD HANDHELD GPS READING |
|---|---|---|---|
| Northeast | 30(/18) | (a) Transects on the outer reef slope started approximately 250 m north of the point were Site 30 was located and ran in a southerly direction.<br>(c) Transects on the inner reef slope commenced at approximately the same latitude (in the vicinity of 1992 Site 18) and ran in a southerly direction. | (a) 2° 57.13' N; 131° 50.54' E<br>(c) 2° 57.17' N; 131° 49.44' E |
| Southeast | 29 | (a) Transects on the outer reef slope started approximately 250 m north of the point were 1992 Site 29 was located and ran in a southerly direction.<br>(c) Transects on the inner reef slope were done on the lagoon side of a bar reef parallel to the inner reef slope north of 1992 Site 23 and ran in a southerly direction. | (a) 2° 50.72' N; 131° 48.58' E<br>(c) 2° 50.70' N; 131° 47.72' E |
| Northwest | 15(/16) | (a) Transects on the outer reef slope started directly adjacent to the stern of the big shipwreck on the NW side and ran in a northerly direction.<br>(b) Transects on the reef flat started approx 150m from the wreck where the two upright stern masts lined up forming a line perpendicular to the long axis of the ship and ran in a northerly direction.<br>(c) Transects on the inner reef slope also commenced where the two upright stern masts lined up forming a line perpendicular to the long axis of the ship and ran in a southerly direction. | (a) 2° 56.17' N; 131° 46.05' E<br>(b) 2° 56.20' N; 131° 46.24' E<br>(c) 2° 56.12' N; 131° 46.79' E |
| Southwest | 21 | (a) There were no obvious reef features at this site. Transects on the outer reef slope commenced at the GPS location and proceeded in a northerly direction.<br>(b) Transects on the reef flat were located approximately 150m from the outer reef slope site. To avoid large expanses of sand flat, one transect ran in a northerly direction and the remaining four ran in a southerly direction. An additional macroinvertebrate survey was conducted nearer to the outer reef slope from this area in a depth of 2m.<br>(c) Transects on the inner reef slope commenced directly across from the outer reef slope site. | (a) 2° 51.46' N; 131° 43.75' E<br>(b) n/a<br>(c) 2° 51.40' N; 131° 44.24' E |
| Patch reefs | 22 | Three patch reefs were surveyed on the reef slope for both fish, corals and macroinvertebrates:<br>(a) Site 22a (P22 in figures) – 1 transect on east side<br>(b) Site 22b (P2 in figures) – 2 transects on east side<br>(c) Site 22c (P3 in figures) – 2 transects on east side | (a) 2° 50.66' N; 131° 45.73' E<br>(b) 2° 50.22' N; 131° 45.57' E<br>(c) 2° 50.53' N; 131° 45.35' E |

*Table 16.12. Summary of 1992 Southwest Island REA survey sites (from Maragos et al., 1994). Repeated in 2000. Source: Helen Reef Project.*

| 2000 SITE NAME | 1992 SITE NAME | FISH | MACRO INVERTEBRATES | BENTHIC VIDEOS | CORAL RECRUITMENT | 2000 HANDHELD GPS READING |
|---|---|---|---|---|---|---|
| 9 North | 9 | X | X | X | X | 2° 52.6583' N; 131° 44.23' E |
| 10 | 10 | X | - | - | - | - |
| 11 | Near 11 | X | - | - | X | 2° 58.11' N; 131° 48.75' E |
| -- | 12 | - | - | - | - | - |
| -- | 13 | - | - | - | - | - |
| -- | 14 | - | - | - | - | - |
| 15 inside | 15/16 | X | X | X | X | 2° 56.12' N; 131° 46.79' E |
| -- | 17 | - | - | - | - | - |
| 19 | 19 | X | - | - | - | - |
| 20 | 20 | X | - | - | - | - |
| 21 inside | 21 | X | X | X | - | 2° 51.40' N; 131° 44.24' E |
| 21 (outside) | - | X | X | X | X | 2° 51.46' N; 131° 43.75' E |
| 22a<br>22b<br>22c | 22 (Expanded to include 3 patch reefs) | X | X | X | X | **22a:** 2° 50.66' N;131° 45.73' E<br>**22b:** 2° 50.22' N;131° 45.57' E<br>**22c:** 2° 50.53' N;131° 45.35' E |
| - | 23 | - | - | - | - | - |
| 24 | 24 | X | - | - | - | - |
| **25** | **25** | **X** | - | **X** | - | - |
| -- | 262 | - | - | - | - | - |
| -- | 27 | - | - | - | - | - |
| 28 | 28 | X | - | - | - | 2° 48.08' N; 131° 44.56' E |
| 29 (outside) | 29 | X | X | X | X | 2° 50.72' N; 131° 48.58' E |
| 29 (inside) | - | X | X | X | X | 2° 50.70' N; 131° 47.72' E |
| 30 (outside) | 30 | X | X | X | X | 2° 57.13' N; 131° 50.54' E |
| 30 (inside) | 18 | X | X | X | - | 2° 57.17' N; 131° 49.44' E |

## Management of the Northern Reef

The Northern Reef encompass an area, approximately 200 km², of enclosed reefs and lagoons situated between the land masses of Ngerchelong State, on the main island of Babeldoab and Kayangel State, the northernmost atoll in the archipelago. This complex system of reefs is known throughout Palau for its rich marine biodiversity and spawning aggregations. As such, the Northern Reef has seen an increase in fishing activity, not only by fishermen from those two states, who own the resources but from other states throughout Palau. This mounting fishing pressure prompted Ngerchelong State to request that PCS conduct a baseline biological survey of the area. Results are presented in Tables 16.13 and 16.14.

*Table 16.13. Species surveyed at Northern Reefs, Palau. Source: PCS.*

| | Bumphead parrotfish | Humphead wrasse | Orange-spine unicornfish | Blue-Spine unicornfish | Red snapper | Humpback snapper | Squaretail grouper | Camouflage grouper | *Epinephelus fuscoguttatus* |
|---|---|---|---|---|---|---|---|---|---|
| Number of fish counted | 907 | 168 | 1661 | 245 | 1,715 | 6,230 | 177 | 222 | 9 |
| Density (#/ km²) | 14.9 | 2.8 | 27.4 | 4.0 | 28.3 | 102.6 | 2.9 | 3.7 | 0.1 |

*Table 16.14. Family groups surveyed at Northern Reefs, Palau. Source: PCS.*

| | Parrotfish | Surgeonfish | Rabbitfish | Emperors | Sweetlips | Sharks | Turtles |
|---|---|---|---|---|---|---|---|
| Number of fish counted | 3,804 | 2,709 | 708 | 428 | 395 | 48 | 19 |
| Density (#/ km²) | 62.7 | 44.6 | 11.7 | 7.1 | 6.5 | 0.8 | 0.03 |

In August of 2006, PCS collaborated with Coral Reef Research Foundation (CRRF) and Ngerchelong State conservation officers to complete a marine biological resource survey of the Northern Reefs. The main objective of this survey was to document the general condition of the area in terms of fish abundance and distribution (Tables 16.13 and 16.14) and substrate coverage. The secondary objective was to map potential scuba diving/snorkeling locations, sport fishing sites and other recreational areas for tourism to increase economic development for the two states in the future. The results are currently being analyzed and will be presented to Ngerchelong and Kayangel States for use in management of the area.

### Protected Area Network Act

The Protected Areas Network (PAN) Act of 2003 aims to support Palauan state government efforts to protect marine resources. This law creates a nationally sanctioned framework by which NGOs and local governments can coordinate marine reserve conservation initiatives through a system of protected areas, which collectively preserve marine biodiversity. It is hoped that the PAN Act will encourage the designation of new MPAs by state governments. Until recently, state governments have designated MPAs, but there was no system for collaboration and support from the national government in identifying appropriate areas or designating and maintaining these resources. A PAN coordinator was appointed to facilitate the implementation of this law. With technical assistance from TNC in the form of a PAN counterpart, the state governments will have access to technical expertise and financial resources that are often lacking at the local level to properly develop MPAs. Recently, the PAN office finalized the drafting of the regulations, which are a requirement under the PAN Act and a precondition for nominating sites for the PAN. In February 2007, the Minister of Resources and Development signed the regulations, and the PAN office has started to assists the states in nominating existing sites for the PAN.

The results of the sustainable financing study, which was completed in 2005/2006, formed the basis for the ongoing revision of the PAN Act to ensure sustainable financing of the PAN. The draft revised PAN Act also ensures that traditionally designated areas are eligible for inclusion. In addition, the revised Act also recognizes that the PAN represents the implementation of the Micronesia Challenge in Palau. The revised PAN Act is currently under consideration by the House of Delegates.

### Micronesia Challenge

In March 2006, at the Eighth Conference of the Parties to the Convention on Biological Diversity (CBD), the leaders of the five political entities of Micronesia (Palau, Federated States of Micronesia, Marshall Islands, Northern Mariana Islands and Guam) launched the Micronesia Challenge: a shared commitment to “effectively conserve at least 30% of the nearshore marine and 20% of the forest resources across Micronesia by 2020.” This commitment will contribute to global and national targets set out in the Millennium Development Goals, Johannesburg Plan of Implementation for the World Summit on Sustainable Development, Mauritius Strategy for Small Island Developing States, U.S. Coral Reef Task Force National Plan of Action and relevant Programmes of Work of the CBD. In order to implement the Micronesia Challenge, leaders, resource managers, community representatives and technical experts from around the region participated in a planning meeting in Palau in December 2006. The objectives of the meeting included: designating regional coordinating and fundraising mechanisms; establishing sustainable financing mechanisms; developing a clear understanding of the terms of the Micronesia Challenge; establishing key targets and milestones to measure progress region-wide; identifying additional skills and knowledge that will be required for successful implementation; and developing a plan for expanding communication and interaction with local communities and traditional leadership. The Micronesia Challenge provides a once-in-a-generation opportunity to significantly “ramp up” biodiversity conservation efforts in Micronesia. In light of this, a team of key regional, international and U.S. federal agency partners has been formed to assist jurisdictions on their implementation efforts.

### MPA Effectiveness

PICRC is currently conducting research to assess the efficacy of several MPAs in Palau. In 2007, TNC was invited to assess the effectiveness of the Rock Islands Southern Lagoon management plan three years after its implementation. Additionally, TNC along with PICRC conducted a day long workshop to underscore the importance of considering management efficacy during the initial stages of plan development. In the future, MPAs will be selected based on the level of management, geographic distribution, size, the protection time frame, and willingness of managers and community members to be evaluated. Ultimately, the objective is to improve the management of MPAs in Palau, thereby making MPAs more effective in meeting their goals and objectives.

PCS, in partnership with TNC, has also established several monitoring sites in four community-designated MPAs in Babeldaob. The monitoring program tracks the abundance of locally important fish and invertebrate species (Table 16.15).

### Other Management Tools

The Palau BMR has deployed fish aggregating devices in territorial waters around Palau in order to take fishing pressure off the reefs and promote a shift to pelagic fisheries. Mooring buoys have been installed throughout the state of Koror as a management tool to decrease recreational impacts on coral reefs. Mooring buoys are well used by dive operators, recreational fishers and boaters. Outside MPAs and other managed areas with very specific regulations, fishing is nationally regulated. Size restrictions exist for lobster. Recently the government enacted a bill fully protecting the humphead wrasse and bumphead parrotfish. The harvest of grouper is restricted to non-peak spawning months and the season is well established. Additionally, the commercial export of reef fish and crustaceans is prohibited. Other restrictions are in

*Table 16.15. Community-designated Conservation Areas. Source: PICRC.*

| MARINE PROTECTED AREA | STATE GOVERNMENT | INDICATORS |
|---|---|---|
| Ngelukes Conservation Area | Ngchesar State | Reef fish and invertebrate species abundance (rabbitfish, snappers, surgeonfish, giant clams and sea cucumbers) |
| Ngermasech Conservation Area | Ngardmau State | Reef fish and invertebrate species abundance (rabbitfish, snappers, surgeonfish, giant clams and sea cucumbers) |
| Ebiil Channel Conservation Area | Ngarchelong State | Abundance of groupers at spawning aggregation sites |
| Ngaruangel Reserve | Kayangel State | Fish abundance, occurrence of nesting sea turtle and sea bird populations |

place, such as a closed season on harvesting sea turtles and full protection for dugongs in Palau.

### Regional Collaboration

For the past three years, PICRC, through the support of NOAA and Japan International Cooperative Agency, has conducted coral reef monitoring training for all of the Freely Associated States (Republic of Palau, Federated States of Micronesia and The Marshall Islands)

From 2005 to 2007, NOAA's Coral Reef Conservation Program and PICRC collaborated with local, regional, and international organizations to build capacity in coral reef ecosystem monitoring in the Freely Associated States of Micronesia. Micronesia is one of the most diverse and resilient coral reef regions in the world and arguably one of the better investments for coral reef conservation. A bottom-up approach was emphasized, focusing on relationship-building and skill development over three years. Forty-three members of Micronesia's governmental regulatory agencies (e.g., Marine Resources Division and Environmental Protection Agencies), local NGOs, and academic institutions were trained over three summers in coral and fish taxonomy, reef sampling methods, experimental design, statistical analyses, database management and reporting. Through continued support from NOAA's National Coral Reef Ecosystem Monitoring Program, the states of Chuuk, Kosrae, Palau, Pohnpei, and Yap and the Republic of Marshall Islands are now beginning to implement a standardized monitoring protocol to monitor their coral and fish resources. This type of monitoring program, combined with traditional management practices in Micronesia, will provide long-term ecosystem-based management in this coral reef setting.

## OVERALL CONCLUSIONS AND RECOMMENDATIONS

Efforts to assess biological and physical aspects of coral reef ecosystems and marine resources in Palau have improved since 2005 edition of this report. Since social, cultural, economic and political factors were identified as extremely important to the success of management strategies, PICRC has taken the lead in coral reef monitoring in and around MPAs. PCS has implemented complementary efforts and leads efforts to assess fish abundance in all the MPAs at the request of communities around Palau. Different organizations are also taking part in both the biological and physical assessment of the reefs and marine resources around Palau.

As Golbuu et al. stated in the 2005 report, the importance of improving communication among the different agencies and groups that are involved in coral reef monitoring, management and conservation at all levels should be considered. To eliminate duplication of work in each community and the resulting frustration by community members, collaboration among agencies and organizations should be improved.

## REFERENCES

Andrew, W. 2007. Long-term Monitoring at Helen Reef Atoll, Palau. pp 51-58. In: H. Kayanne, M. Omuri, K. Fabricius. E. Verheij, P. Colin, Y. Golbuu, and H. Yukihira (eds.). Coral Reefs of Palau. Palau International Coral Reef Center. Koror, Palau. 231 pp.

Brazaitis, P.J., J. Eberdong, and P.J. Brazaitis. 2003. The Saltwater Crocodile, *Crocodylus porosus*, in the Republic of Palau. A special report to the U.S. Fish and Wildlife Service and The Nature Conservancy. 23 pp.

Bryant, D., L. Burke, J. McManus, and M. Spalding. 1998. Reefs at Risk: A map-based indicator of threats to the world's coral reefs. World Resources Institute. 56 pp.

Bureau of Marine Resources. 2005. Draft Report. Palau Ministry of Resources and Development. Koror, Palau. 32 pp.

Bureau of Marine Resources. Unpublished database. Palau Ministry of Resources and Development. Koror, Palau.

Colin, P.L. 1997. Report of visit to the location of the grounding of the container ship Kyowa Violet, Ngeremlengui State, Republic of Palau, August 4, 1997. Report to Palau Environmental Quality Protection Board. Koror, Palau. 4 pp.

Colin, P.L. 2006a. Preliminary report on reef damage due to the grounding of the USNS Niagara Falls, Ngatpang State, Republic of Palau. Report to Ngatpang State Government, Republic of Palau. 10 pp.

Colin, P.L. 2006b. Preliminary report on reef damage due to the grounding of Tawinese naval frigate 1103 on a coral reef, Ngatpang State, Palau. Report to Ngatpang State Government, Republic of Palau. 5 pp.

Colin, P.L. 2007. Update (January 2007) on the October 2005 Grounding of the USNS Niagara Falls, Ngatpang State, Republic of Palau. Report to Ngatpang State Government, Republic of Palau. 8 pp.

Eberdong, J. Bureau of Marine Resources, Ministry of Resource and Development. Koror, Palau. Personal communication.

Golbuu, Y. 2000. Status of Coral Reefs of Palau. PCC-CRE Publication 19/00. Palau Community College. Koror,Palau, 54 pp.

Golbuu, Y., G. Mereb, D. Uehara, A. Bauman, and J. Umang. 1999. Biological survey at Ngerumekaol, Koror State, Republic of Palau. PCC-CRE Publication 17/99. Palau Community College. Koror, Palau. 23 pp.

Golbuu, Y., A. Bauman, J. Kuartei, and S. Victor. 2005. The State of Coral Reef Ecosystems of Palau. pp. 488-507. In: J.E. Waddell (ed.). The State of Coral Reef Ecosystems of the United States and Pacific Freely Associated States: 2005. NOAA Technical Memorandum NOS NCCOS 11. 522 pp.

Golbuu, Y., K.E. Fabricius, and K. Okaji. 2007a. Status of Palau's coral reefs in 2005, and their recovery from the 1998 bleaching event. pp. 40-50. In: H. Kayanne, M. Omuri, K. Fabricius. E. Verheij, P. Colin, Y. Golbuu, and H. Yukihira (eds.). Coral Reefs of Palau. Palau International Coral Reef Center. Koror, Palau. 231 pp.

Golbuu, Y., S. Victor, L. Penland, D. Idip Jr., C. Emaurois, K. Okaji, H. Yukihira, A. Iwase, and R. van Woesik. 2007b. Palau's coral reef show differential habitat recovery following the 1998-bleaching event. Coral Reefs 26: 319-322.

Harvell, C., K. Kim, J. Burkholder, R. Colwell, P. Epstein, D. Grimes, E. Hofmann, E. Lipp, A. Osterhaus, R. Overstreet, J. Porter, G. Smith, and G. Vasta. 1999. Emerging marine diseases: Climate links and anthropogenic factors. Science 285(5433): 1505-1510.

Kayanne, H., M. Omori, K. Fabricius, E. Verheij, P. Colin, Y. Golbuu, and H. Yukihira (eds.). 2007. Coral Reefs of Palau. Palau International Coral Reef Center. Koror, Palau. 231 pp.

Kitalong, A. and J. Eberdong. 2006. Palau Marine Turtle Conservation and Management Project. Palau Bureau of Marine Resources. Koror, Palau. 69 pp.

Klain, S. Bureau of Marine Resources, Ministry of Resource and Development. Koror, Palau. Personal Communication.

Maragos, J.E., C. Birkeland, C. Cook, K. Des Rochers, R. Di Rosa, T.J. Donaldson, S.H. Geermans, M. Guilbeaux, H. Hirsh, L. Honigman, N. Idechong, P.S. Lobel, E.Matthews, K.J. McDermid, K.Z. Meier, R. Myers, D. Otobed, R.H. Richmond, B. Smith, and R. Smith. 1994. Marine and Coastal Areas Survey of the Main Palau Islands: Part 2 Rapid Ecological Assessment Synthesis Report. Prepared by CORIAL and The Nature Conservancy. 125 pp.

Matthews, L. 2004. Subsistence Fishing Activities in the Rock Islands. Palau Conservation Society. PCS Report No. 2004-01.

Palau Conservation Society. 1999. Resource surveys of Ngemai Reef, Ngiwal, 1997-1998. PCS Report 99-01. 16 pp. .

Palau International Coral Reef Center. 2006. Rapid Assessment of ship grounding (Kamaneka 212) at Techeraech Reef on Uchelbuu Barrier Reef. Palau International Coral Reef Center. Koror, Palau.

Palau Visitors Authority. 2001. Comprehensive exit survey analysis report. Palau Visitors Authority Report. 45 pp.

Ridep-Morris, A. 2004. Coastal Fisheries National Report for the Republic of Palau.

Tervet, I. 2005. Operation Big Eye - Marine Law Enforcement Report. Republic of Palau.

The Environmental, Inc. (TEI). 1999. Palau Inshore Fisheries Profile  TEI Publication #0499 26 pp.

The Environmental, Inc. (TEI). 2003. Resource Use Study. Office of Environmental Response and Coordination.

The Palau Conservation Society. 2000. Profiles of Palau's Inshore Fisheries, 1989-1998. 28 pp.

Victor, S., Y. Golbuu, E. Wolenski, and R.H. Richmond. 2004. Fine Sediment Trapping in Two Mangrove-Fringed Estuaries Exposed to Contrasting Land-Use Intensity, Palau, Micronesia. Wetlands Ecol. Manage. 12: 277-283.

Willis, B. James Cook University, Townsville, Australia. Personal Communication.

Willis, B.L., C.A. Page, and E.A. Dinsdale. 2004. 3. Coral disease on the Great Barrier Reef. pp. 69-104. In: E. Rosenberg and Y. Loya (eds.). Coral Health and Disease. Springer, Berlin, Heidelberg, New York. 488 pp.

Yukihira, H., K. Shimoike, Y. Golbuu, T. Kimura, S. Victor, and H. Ohba. 2007. Coral Reef Communities and Other Marine Biotopes in Palau. pp. 10-29. In: H. Kayanne, M. Omuri, K. Fabricius. E. Verheij, P. Colin, Y. Golbuu, and H. Yukihira (eds.). Coral Reefs of Palau. Palau International Coral Reef Center. Koror, Palau. 231 pp.

# NATIONAL SUMMARY

Jeannette Waddell[1], Laurie Bauer[1], Alicia Clarke[1], Sarah Hile[1], Matthew Kendall[1] and Charles Menza[1]

The National Summary assesses and compares the condition of coral reef ecosystems across all 15 jurisdictions in the United States and Pacific Freely Associated States using a common framework and provides a broad measure of ecosystem status and response. Since there are no standardized monitoring programs, methods or data sets that can be used to compare the state of coral reef ecosystems across all jurisdictions, the contents of this summary chapter are instead based on the knowledge and expert opinion of coastal managers and scientists who are responsible for monitoring and managing coral reef ecosystems within each jurisdiction. Consequently, data used for the National Summary represent the evaluations of those who are most knowledgeable about the condition of coral reef ecosystem resources in each jurisdiction, threats posed to those resources and the data available to quantify coral reef ecosystem condition.

Standardized information was collected using a multiple-choice questionnaire that was completed by each jurisdiction's report coordinator and/or writing team. A review of the individual chapters in this report resulted in the identification of four key resources and ten commonly addressed threats and the incorporation of these topics in the questionnaire (Table 17.1). These 14 topics represent important aspects of coral reef ecosystem condition, function, dynamics and resilience. In the questionnaire, respondents evaluated the present condition, short-term trend, long-term trend, and their ability to monitor these threats and resources within their entire jurisdiction, not just in the locations that have been intensively studied.

The questionnaire and instructions for completion can be found in Appendix A and are briefly described here. Respondents were asked to describe the present level of impact from each of the ten threats using the following categories: absent, low, medium, high or unknown. Present resource conditions were described as poor, fair, good, excellent and unknown. Temporal trends in resources and threats were described as increasing, about the same, decreasing, not applicable and unknown. Trends were described for two time scales respectively: over the last three years (i.e., since the 2005 Coral Report) and over the last 10-25 years. The ability to monitor each threat and resource was indicated using the categories: poor, fair, good, excellent and unknown. Appendix B contains the responses received from each jurisdiction.

*Table 17.1. Key resources and threats identified for use in the national summary questionnaire completed by each jurisdiction's report coordinator and/or writing team.*

**Key Resources**

- Water Quality
- Living Coral Cover
- Reef Fish Populations
- Harvested Reef Fish and Macroinvertebrates

**Commonly Addressed Threats**

- Climate Change and Coral Bleaching
- Coral Disease
- Tropical Storms
- Coastal Development
- Tourism and Recreation
- Commercial Fishing
- Subsistence and Recreational Fishing
- Vessel Damage
- Marine Debris
- Aquatic Invasive Species

Questionnaire responses were mapped to show spatial patterns in resource condition and high threats among jurisdictions (Figures 17.1 and 17.2). Preliminary evaluation of the responses revealed a regional difference between the Pacific and Caribbean/Atlantic/Gulf of Mexico in threat levels and resource conditions. Responses were therefore tallied separately within these regions (Tables 17.2 and 17.3) and averaged to determine the regional condition of each resource and threat. In contrast, there was generally no difference between the Pacific and Caribbean/Atlantic/Gulf of Mexico regions in terms of the trends observed over time or their ability to monitor threats or resources. Therefore, responses to these questions were tallied across all 15 jurisdictions and then averaged to determine the overall trend (Table 17.4 and 17.5) and U.S. monitoring ability (Table 17.6), respectively.

---

[1] NOAA National Ocean Service, Center for Costal Monitoring and Assessment, Biogeography Branch

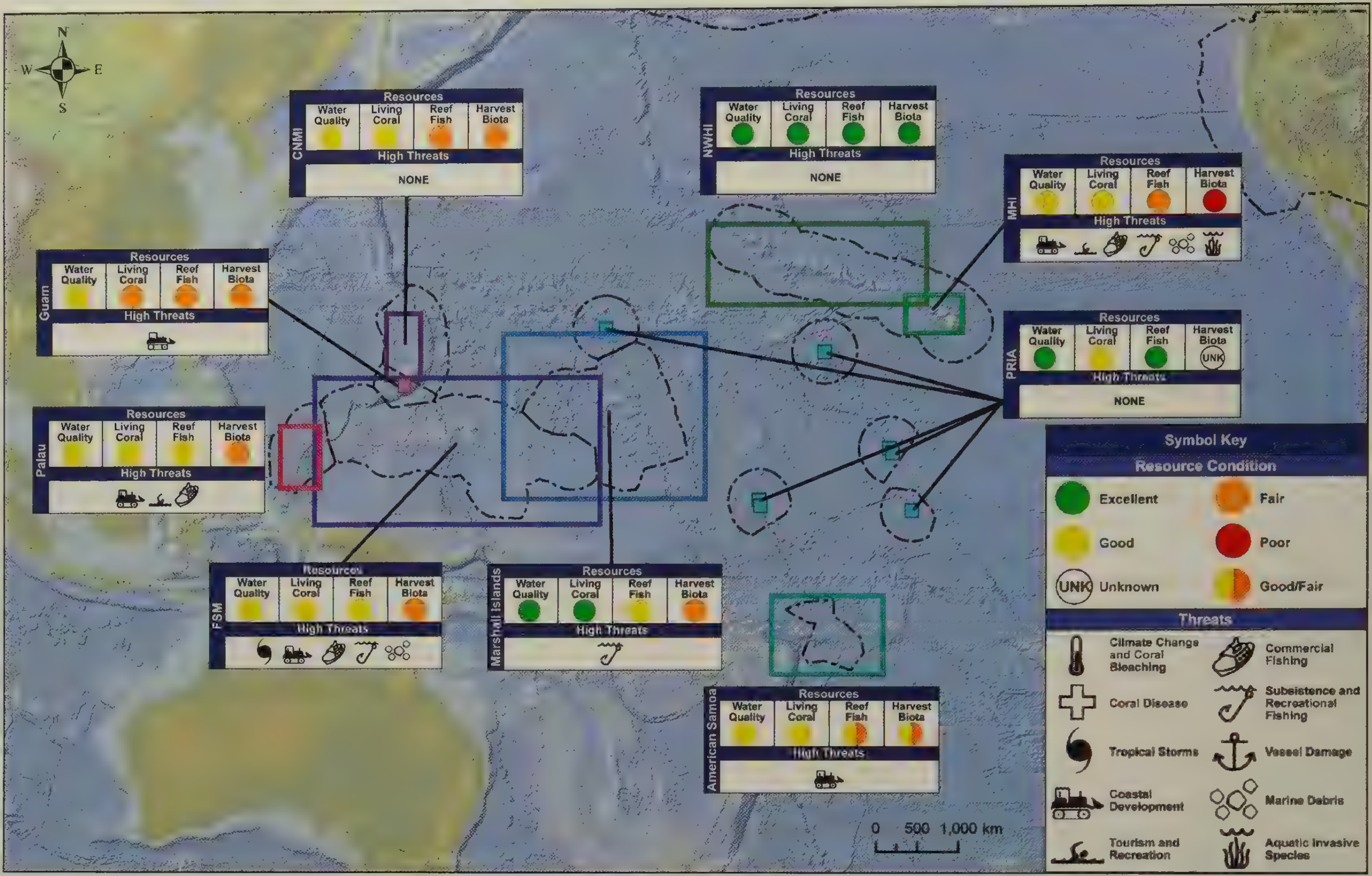

N
W
E
S
CNMI
NWHI
MHI
Guam
PRIA
Palau
FSM
Marshall Islands
American Samoa
Resources
Water Quality
Living Coral
Reef Fish
Harvest Biota
High Threats
NONE
UNK
Symbol Key
Resource Condition
Excellent
Fair
Good
Poor
Unknown
Good/Fair
Threats
Climate Change and Coral Bleaching
Commercial Fishing
Coral Disease
Subsistence and Recreational Fishing
Tropical Storms
Vessel Damage
Coastal Development
Marine Debris
Tourism and Recreation
Aquatic Invasive Species
0
500
1,000 km

Figure 17.1. Survey results describing the present condition of four key resources and indicating the threats ranked as "high" in the Pacific region. Results are displayed in a map format to elucidate regional differences among jurisdictions. Map: C. Menza and S. Hile.

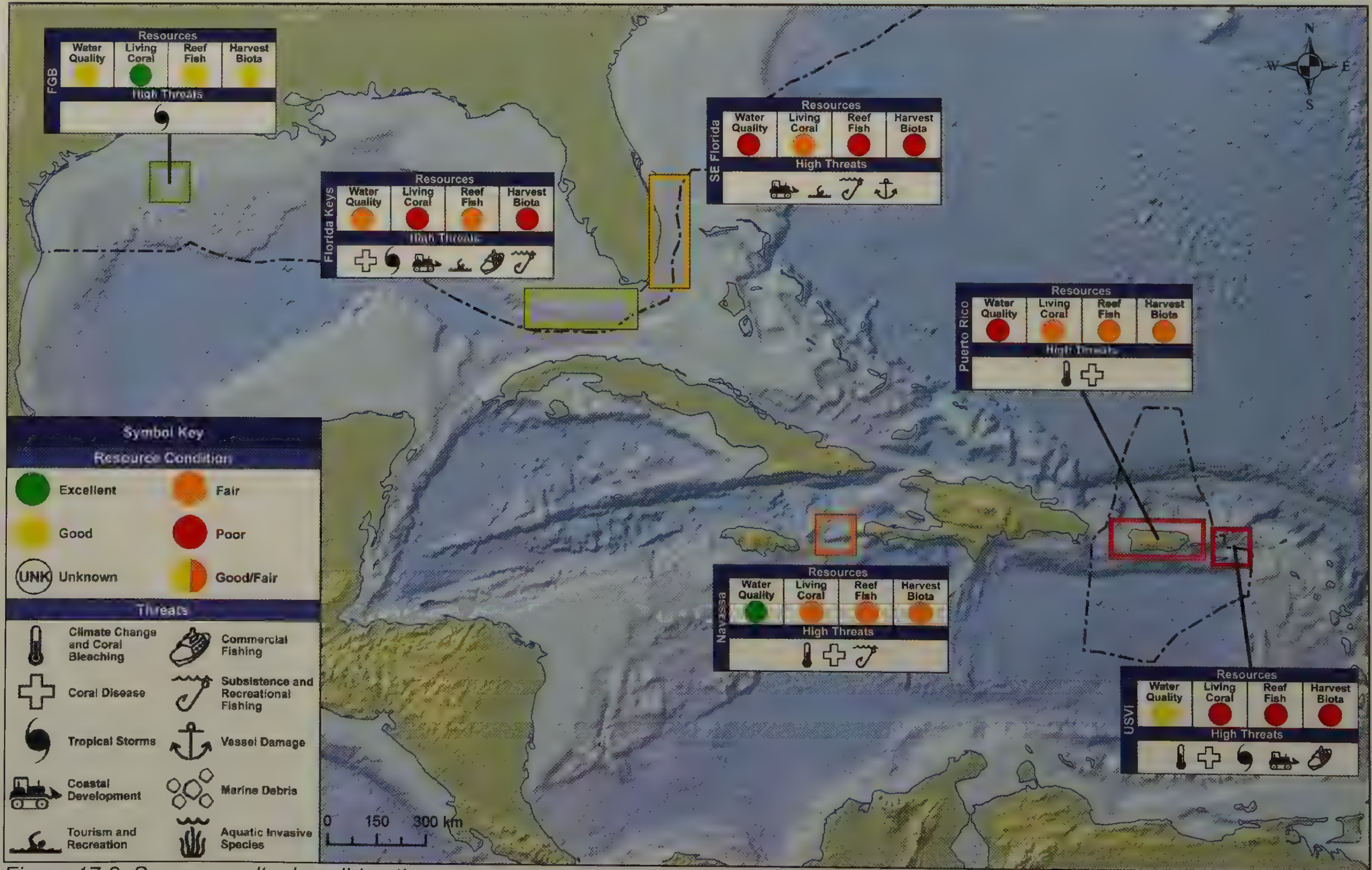

FGB
SE Florida
Florida Keys
Puerto Rico
Navassa
USVI
Resources
Water Quality
Living Coral
Reef Fish
Harvest Biota
High Threats
N
W
E
S
Symbol Key
Resource Condition
Excellent
Fair
Good
Poor
Unknown
Good/Fair
Threats
Climate Change and Coral Bleaching
Commercial Fishing
Coral Disease
Subsistence and Recreational Fishing
Tropical Storms
Vessel Damage
Coastal Development
Marine Debris
Tourism and Recreation
Aquatic Invasive Species
0
150
300 km

Figure 17.2. Survey results describing the present condition of four key resources and indicating the threats ranked as "high" in the Atlantic region. Results are displayed in a map format to elucidate regional differences among jurisdictions. Map: C. Menza and S. Hile.

*Table 17.2. Number of the nine Pacific jurisdictions reporting overall resource and threat condition in each category summarized across jurisdictions. Overall conditions were determined by averaging the responses in each row, based on the values poor or high=0, fair and medium=1, good and low=2, and excellent and absent=3. Unknown responses were not included in the average.*

| | | UNKNOWN | POOR | FAIR | GOOD | EXCELLENT | OVERALL |
|---|---|---|---|---|---|---|---|
| Resources | Water Quality | 0 | 0 | 0 | 6 | 3 | GOOD |
| | Living Coral Cover | 0 | 0 | 1 | 6 | 2 | GOOD |
| | Reef Fish Populations | 0 | 0 | 3 | 4 | 2 | GOOD |
| | Harvested Reef Fish and Macroinvertebrates | 1 | 1 | 5 | 1 | 1 | FAIR |

| | | UNKNOWN | HIGH | MED | LOW | ABSENT | OVERALL |
|---|---|---|---|---|---|---|---|
| Threats | Climate Change and Coral Bleaching | 0 | 0 | 8 | 1 | 0 | MED |
| | Coral Disease | 0 | 0 | 3 | 6 | 0 | LOW |
| | Tropical Storms | 0 | 1 | 3 | 5 | 0 | MED |
| | Coastal Development | 0 | 5 | 2 | 2 | 0 | MED |
| | Tourism and Recreation | 0 | 2 | 3 | 4 | 0 | MED |
| | Commercial Fishing | 0 | 3 | 3 | 3 | 0 | MED |
| | Subsistence and Recreational Fishing | 0 | 3 | 3 | 3 | 0 | MED |
| | Vessel Damage | 0 | 0 | 4 | 5 | 0 | LOW |
| | Marine Debris | 0 | 2 | 6 | 1 | 0 | MED |
| | Aquatic Invasive Species | 0 | 1 | 3 | 5 | 0 | MED |

*Table 17.3. Number of the six Caribbean/Atlantic/Gulf of Mexico jurisdictions reporting overall resource and threat condition in each category summarized across jurisdictions. Overall conditions were determined by averaging the responses in each row, based on the values poor or high=0, fair and medium=1, good and low=2, and excellent and absent=3. Unknown responses were not included in the average.*

| | | UNKNOWN | POOR | FAIR | GOOD | EXCELLENT | OVERALL |
|---|---|---|---|---|---|---|---|
| Resources | Water Quality | 0 | 2 | 1 | 2 | 1 | FAIR |
| | Living Coral Cover | 0 | 2 | 3 | 0 | 1 | FAIR |
| | Reef Fish Populations | 0 | 2 | 3 | 1 | 0 | FAIR |
| | Harvested Reef Fish and Macroinvertebrates | 0 | 3 | 2 | 1 | 0 | FAIR |

| | | UNKNOWN | HIGH | MED | LOW | ABSENT | OVERALL |
|---|---|---|---|---|---|---|---|
| Threats | Climate Change and Coral Bleaching | 0 | 3 | 1 | 2 | 0 | MED |
| | Coral Disease | 0 | 4 | 0 | 2 | 0 | MED |
| | Tropical Storms | 0 | 3 | 2 | 1 | 0 | MED |
| | Coastal Development | 0 | 3 | 1 | 1 | 1 | MED |
| | Tourism and Recreation | 1 | 3 | 1 | 2 | 0 | MED |
| | Commercial Fishing | 2 | 2 | 2 | 0 | 0 | HIGH |
| | Subsistence and Recreational Fishing | 1 | 2 | 2 | 0 | 0 | HIGH |
| | Vessel Damage | 0 | 3 | 2 | 2 | 1 | MED |
| | Marine Debris | 0 | 1 | 4 | 2 | 0 | MED |
| | Aquatic Invasive Species | 0 | 0 | 2 | 4 | 0 | LOW |

## Present Condition of Resources and Status of Threats

Responses indicated that resource conditions in the Pacific were better than in the Caribbean/Atlantic/Gulf of Mexico (Figure 17.3). The majority of resources in the Caribbean/Atlantic/Gulf of Mexico region were listed as poor or fair condition. Only six of the 24 responses (25%) reported that conditions were good or excellent. These exceptions included water quality in Navassa and the USVI, and live coral cover, reef fish populations, and harvested fish and invertebrate populations in the Flower Garden Banks (FGB). The fact that FGB had the best condition of resources, generally speaking, and is the most remote jurisdiction in the region should not be overlooked.

In contrast to the Caribbean/Atlantic/Gulf of Mexico region, the majority (69%) of resources in the Pacific region were listed as in good or excellent condition. The condition of harvested reef fish and macroinvertebrates was the only metric to be classified by the majority of Pacific jurisdictions as fair and the only metric to be listed in poor condition (Main Hawaiian Islands).

Threats were considered slightly greater in the Caribbean/Atlantic/Gulf of Mexico relative to values reported in the Pacific (Figure 17.3). More threats were ranked as high in the Caribbean region (average of 3.5 per jurisdiction) than in the Pacific region (average of 1.89 per jurisdiction). Although the majority of overall threat levels were medium in both regions, the Caribbean/Atlantic/Gulf of Mexico had two threats with overall high levels (both associated with fishing), whereas there were no overall threat levels listed as high for the Pacific. In fact, no Pacific jurisdiction indicated that coral disease or vessel grounding posed a high threat to coral reef ecosystems, and the majority considered both of these threats to be present at a low level.

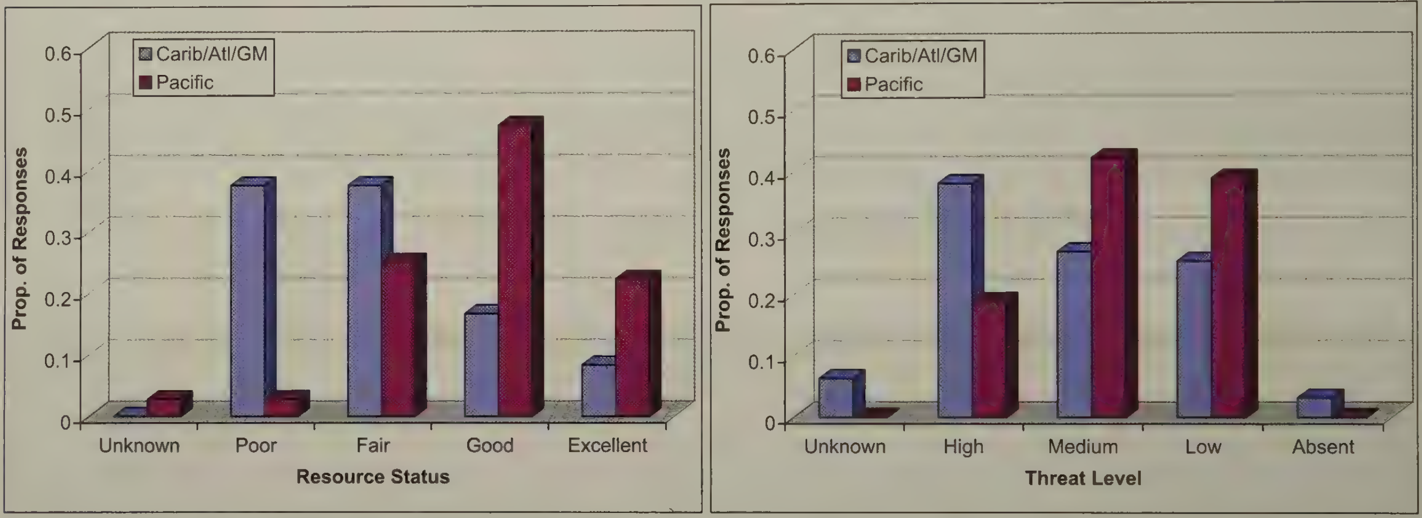


*Figure 17.3. The left panel shows the distribution of responses used to describe the present status of the four key resources in the Pacific and Caribbean/Atlantic/Gulf of Mexico regions. The right panel illustrates the ranking of the threat level that each of the 10 common threats poses to the jurisdictions in both regions. See Appendix B for jurisdiction-specific responses. Graphs: C. Menza.*

## Trends in Resource Condition and Threat Level

Since the last reporting effort (2005), the condition of resources declined, while threats in the majority of jurisdictions have been increasing (Table 17.4). For about half of the jurisdictions, threats such as climate change/coral bleaching, coral disease, and tourism and recreation have not changed significantly over the last three years, but have increased over the past 10-25 years (Table 17.5). Few jurisdictions described any threats as decreasing. Similarly, although the average condition of most resources declined over both the short- and long-term time periods, more jurisdictions reported a declining trend over 10-25 years than over the past 3 years. The majority of jurisdictions that reported no long-term change in coral cover, reef fish populations, and harvested reef fish and macroinvertebrates were located in the Pacific.

*Table 17.4. Number of the 15 jurisdictions reporting a trend in the condition of resources or threats over the past 3 years. Overall trends were determined by averaging the responses in each row, based on the values decreasing=-1, about the same=0, increasing=1. Average values between -0.2 and 0.2 were considered about the same. Unknown responses were not included in the average.*

| Resources | DECREASING | ABOUT THE SAME | INCREASING | UNKNOWN | OVERALL |
|---|---|---|---|---|---|
| Water Quality | 5 | 8 | 1 | 1 | Decreasing |
| Living Coral Cover | 5 | 8 | 2 | 0 | Same |
| Reef Fish Populations | 5 | 10 | 0 | 0 | Decreasing |
| Harvested Reef Fish and Macroinvertebrates | 5 | 8 | 0 | 0 | Decreasing |

| Threats | INCREASING | ABOUT THE SAME | DECREASING | UNKNOWN | OVERALL |
|---|---|---|---|---|---|
| Climate Change and Coral Bleaching | 8 | 6 | 0 | 1 | Increasing |
| Coral Disease | 7 | 7 | 0 | 1 | Increasing |
| Tropical Storms | 3 | 12 | 0 | 0 | Same |
| Coastal Development | 8 | 2 | 4 | 0 | Increasing |
| Tourism and Recreation | 8 | 6 | 0 | 1 | Increasing |
| Commercial Fishing | 5 | 7 | 1 | 2 | Increasing |
| Subsistence and Recreational Fishing | 8 | 5 | 0 | 2 | Increasing |
| Vessel Damage | 3 | 11 | 0 | 0 | Increasing |
| Marine Debris | 5 | 9 | 0 | 1 | Increasing |
| Aquatic Invasive Species | 8 | 7 | 0 | 0 | Increasing |

*Table 17.4. Number of the 15 jurisdictions reporting a trend in the condition of resources or threats over the past 10-25 years. Overall trends were determined by averaging the responses in each row, based on the values decreasing=-1, about the same=0, increasing=1. Average values between -0.2 and 0.2 were considered about the same. Unknown responses were not included in the average.*

| Resources | DECREASING | ABOUT THE SAME | INCREASING | UNKNOWN | OVERALL |
|---|---|---|---|---|---|
| Water Quality | 8 | 4 | 0 | 3 | Decreasing |
| Living Coral Cover | 10 | 3 | 1 | 1 | Decreasing |
| Reef Fish Populations | 8 | 6 | 0 | 1 | Decreasing |
| Harvested Reef Fish and Macroinvertebrates | 10 | 3 | 0 | 1 | Decreasing |

| Threats | INCREASING | ABOUT THE SAME | DECREASING | UNKNOWN | OVERALL |
|---|---|---|---|---|---|
| Climate Change and Coral Bleaching | 13 | 0 | 0 | 2 | Increasing |
| Coral Disease | 11 | 1 | 0 | 3 | Increasing |
| Tropical Storms | 4 | 11 | 0 | 0 | Increasing |
| Coastal Development | 9 | 3 | 2 | 0 | Increasing |
| Tourism and Recreation | 12 | 1 | 1 | 1 | Increasing |
| Commercial Fishing | 5 | 5 | 3 | 2 | Same |
| Subsistence and Recreational Fishing | 11 | 1 | 1 | 2 | Increasing |
| Vessel Damage | 6 | 7 | 1 | 0 | Increasing |
| Marine Debris | 11 | 2 | 0 | 2 | Increasing |
| Aquatic Invasive Species | 8 | 4 | 0 | 3 | Increasing |

### *Ability to Monitor*

Many jurisdictions indicated that their ability to monitor their key resources and threats to them was fair (Figure 17.4; Table 7.6). Across all resources and threats, 17% of the responses indicated a poor ability to monitor, 49% were fair, 30% were good and only 3% reported an excellent ability to monitor. Of the four key resources in the questionnaire, only the ability to monitor living coral cover was considered to be good by most of the jurisdictions. Similarly, of the 10 key threats in the questionnaire, the ability to monitor only two of them, climate change/ coral bleaching and tropical storms (both of which are issues local managers can do nothing to mitigate) was considered good on average. Also of note, the ability to monitor three of the key threats, commercial fishing, subsistence and recreational fishing and aquatic invasive species, was considered poor by nearly half of the jurisdictions.

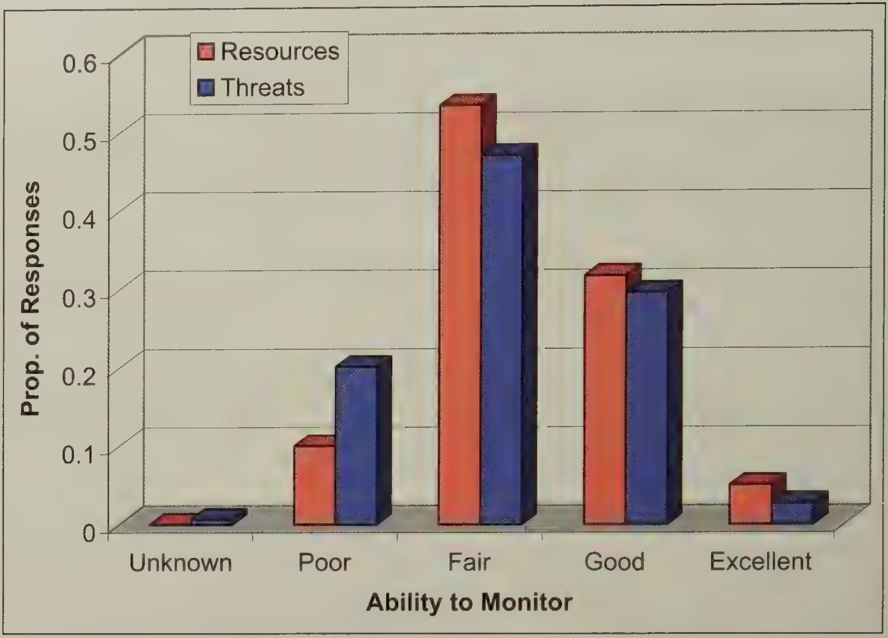


*Figure 17.4. Many jurisdicitons in both the Pacific and Caribbean/Atlantic/Gulf of Mexico rated their ability to monitor resources and threats posed to them as "fair". Graph: C. Menza.*

*Table 17.6. Number of jurisdictions reporting their present ability to monitor each primary resource or key threat summarized across all jurisdictions. Overall ability to monitor was determined by averaging the responses in each row, based on the values poor=0, fair=1, good=2, and excellent=3. Unknown responses were not included in the average.*

| Resources | UNKNOWN | POOR | FAIR | GOOD | EXCELLENT | OVERALL |
|---|---|---|---|---|---|---|
| Water Quality | 0 | 3 | 8 | 4 | 0 | FAIR |
| Living Coral Cover | 0 | 0 | 5 | 9 | 1 | GOOD |
| Reef Fish Populations | 0 | 0 | 11 | 3 | 1 | FAIR |
| Harvested Reef Fish and Macroinvertebrates | 0 | 3 | 8 | 3 | 1 | FAIR |

| Threats | UNKNOWN | POOR | FAIR | GOOD | EXCELLENT | OVERALL |
|---|---|---|---|---|---|---|
| Climate Change and Coral Bleaching | 0 | 0 | 7 | 8 | 0 | GOOD |
| Coral Disease | 0 | 1 | 9 | 4 | 1 | FAIR |
| Tropical Storms | 0 | 1 | 4 | 10 | 0 | GOOD |
| Coastal Development | 0 | 2 | 4 | 6 | 2 | FAIR |
| Tourism and Recreation | 0 | 2 | 10 | 3 | 0 | FAIR |
| Commercial Fishing | 0 | 7 | 6 | 2 | 0 | FAIR |
| Subsistence and Recreational Fishing | 0 | 7 | 5 | 3 | 0 | FAIR |
| Vessel Damage | 0 | 0 | 10 | 4 | 1 | FAIR |
| Marine Debris | 0 | 3 | 9 | 3 | 0 | FAIR |
| Aquatic Invasive Species | 1 | 7 | 6 | 1 | 0 | FAIR |

### *Conclusions*

The least impacted reef ecosystems tend to be those in the most remote locations as indicated by the good resource condition in many of the Pacific jurisdictions relative to the Caribbean/Atlantic/Gulf of Mexico. Similarly, the reefs in poorest condition are located adjacent to areas with large resident and visitor populations that access and exploit reef resources for recreation and profit. It must be noted, however, that even the most remote reefs are exhibiting signs of decline and none can be considered pristine. A conservative take-home message from this assessment is that nearly half of coral reefs of the U.S. and Pacific Freely Associated States are not in good condition and are continuing steadily on a long-term decline.

Another primary conclusion drawn from survey results is that current monitoring activities and the present resources allocated to conducting them are inadequate to provide the information needed by management for decision-making at local and national levels. Although this is the third cycle of reporting on U.S. reef ecosystems since 2002, for many jurisdictions, there is still a critical need to develop robust monitoring strategies, allocate resources and implement field studies. NOAA is presently reviewing the elements of the existing coral monitoring portfolio to determine the most expedient way of generating data to better support management. It is important to recognize that monitoring has come a long way since the creation of the U.S. Coral Reef Task Force in 1998. The yearly dissemination of federal funds to the jurisdictions to support monitoring and development of the chapters in this report series has increased from $0.4 million to $1.1 million since 2002. These steps, while impressive, are apparently insufficient given the magnitude of the task at hand.

It is important to acknowledge that the results of this questionnaire are not based solely on the scientific data presented in the chapters and are subject to biases of the respondents. Until standardized monitoring protocols can be implemented in all jurisdictions at appropriate and consistent temporal and spatial scales, the ability to provide strictly quantitative comparisons across all jurisdictions is limited. This limiting factor is a direct result of the varied evolution of U.S. coral reef monitoring efforts at each jurisdiction. In addition, monitoring capacity, level of taxonomic expertise, management needs and other factors differ widely among jurisdictions. Consequently, no consistently collected metrics exist by which all the jurisdictions can be equally measured and compared. Few data sets are available that span multiple jurisdictions and none span all. Such consistency in measurement and reporting of metrics is needed across all 15 U.S. jurisdictions.

Any attempt to characterize the condition of a resource, especially one based partly on opinion, must acknowledge the problem of shifting baselines. Few, if any, places on earth have escaped impact from human activities and although this report includes uninhabited and remote locations, all sites are subject to global threats, such as climate change. Much of the ecosystem change likely occurred prior to quantitative baseline characterization and lies outside the experience of respondents' paradigms. This affects respondents' perceptions of what a pristine ecosystem should look like and can cause them to judge their resources to be in a less-altered or better condition than they actually are.

Also of note, this summary downplays the many unique but important issues and potential threats to individual jurisdictions. For example, active offshore oil and gas exploration, security training activities and ecological disturbances such as COTS are limited to a few jurisdictions. These issues are reported in detail within corresponding jurisdiction chapters. It is important to recognize that survey responses are not a self-criticism of the effort or ability of the scientists and managers working in each jurisdiction. Resources such as reef fish or coral cover may fluctuate for a number of reasons, including natural variability and anthropogenic impacts. Resource declines can occur despite the diligent efforts of scientists and managers. For example, the passage of a major storm system may alter benthic community composition on a reef, reducing key ecosystem resources despite the diligent efforts of scientists and managers. Similarly, the loss of live coral cover from threats such as coral bleaching and subsequent disease is associated with perturbations of global climate patterns. Global climate change presents urgent challenges for coral reef ecosystem management at the broadest spatial and longest temporal scales. Remedies for global climate change are far beyond measures that can be implemented by local management and require bold actions on an international scale to affect change.

The results of the National Summary clearly indicate that coral reef ecosystem resources continue to be beset by significant threats, many of which have increased and intensified. The present level of action to abate resource declines has not resulted in a positive change in the trajectory of threats to coral reef ecosystems. Without implementation of comprehensive protections for reef ecosystems, reef resources can be expected to continue to decline.

## REFERENCES

National Oceanic and Atmospheric Administration (NOAA). 2002. A National Coral Reef Action Strategy: Report to Congress on implementation of the Coral Reef Conservation Act of 2002 and the National Action Plan to Conserve Coral Reefs in 2002-2003. NOAA. Silver Spring, Maryland. 120 pp. + appendix.

Waddell, J.E. (ed.), 2005. The State of Coral Reef Ecosystems of the United States and Pacific Freely Associated States: 2005. NOAA Technical Memorandum NOS NCCOS 11. NOAA/NCCOS Center for Coastal Monitoring and Assessment's Biogeography Team. Silver Spring, MD. 522 pp.

## APPENDIX A:

# THE STATE OF U.S.AND FAS CORAL REEFS: 2008—NATIONAL SUMMARY

### Questionnaire Instructions

The attached questionnaire was developed to enable comparisons in resources and threats among the many jurisdictions for the National Summary Chapter of the 2008 Coral Report. We designed the PDF questionnaire to fit on a single page and to be easily fill-able using simple multiple choice pull down menus. The entire survey should take less than 1 hour to complete including time for discussion and debate when making your selections. One questionnaire for each jurisdiction is to be filled out by the writing team members and report coordinators within that jurisdiction. Scheduling a short meeting or conference call with key individuals from your jurisdiction is probably the most efficient approach.

The questionnaire is divided into two parts. The first part addresses the condition of 6 target resource metrics (e.g., live coral, reef fish) using four multiple choice questions. The first answer describes the present overall condition of each resource using the pull-down menu choices of poor, fair, good, excellent, and unknown. Please consider each resource comprehensively; for example, reef fish populations in which apex predators or other ecologically important groups were absent probably would not be rated as 'excellent' even if reef fish abundance was high. The next two questions ask you to describe the short and long-term trends in the condition of each resource. Finally, your jurisdiction's ability to monitor/assess each resource is requested, keeping in mind that the objective is to highlight resources for which additional monitoring/ assessment is needed. Please also note that the final two resources, Conservation Practices/ Management Capacity and Benthic Mapping Products, should be interpreted in a slightly different context when answering the fourth question on 'ability to monitor or assess." Think of these questions as more of a self-evaluation of monitoring capacity. For Conservation Practices/ Management Capacity, we want to know if your jurisdiction is making an effort to evaluate the efficacy of management strategies (e.g., MPAs) and actions. For Benthic Mapping Products, we are trying to gauge how well your jurisdiction is able to use the map products and tools available and apply them for research and conservation purposes.

The second part of the questionnaire addresses 10 key threats (e.g., disease, storms) that affect coral ecosystems. For each threat, we ask that you answer four multiple choice questions, which will help determine the level of threat: low, medium, high, absent, or unknown. Threats should be considered relative to each other so the results clearly indicate which threats have the highest level of impact. The first question addresses the overall threat to the jurisdiction (defined as all parts of the jurisdiction, regardless of human settlement patterns or management distinctions). The next two questions address the temporal trend in those threats at two time scales; 1) since the last Coral Report in 2005 and 2) over the last 10-25 years. Choices for these questions are: increasing, about the same, decreasing, not applicable, and unknown. The last question addresses your jurisdiction's capacity to monitor or assess each threat, not necessarily the impact of the threat on resources. The purpose of this last question is not to be critical of current efforts, but to evaluate, on a national level, our collective ability to understand and monitor key threats based on present funding and effort allocation.

Please keep in mind the following as you complete the questionnaire:
Think Comprehensively: We recognize that threat levels and conditions vary within and among islands or regions within a given jurisdiction, and that these differences are elucidated in the individual chapters. We ask that you answer the questionnaire to summarize the threat or resource across the entire jurisdiction.

No single jurisdiction or response to any element of this questionnaire will be dissected or discussed in detail. Your responses will be compiled and summarized with those from all the jurisdictions to obtain a broad national level perspective on threats and resources.

| **Resource / Other** | **The overall condition of ______ in my jurisdiction is...** | **Since the last Coral Report the trend in the condition of ______ is...** | **The long-term (10- 25 yrs) trend in the condition of ______ is...** | **The jurisdictions ability to monitor and/or assess ______ is...** |
|---|---|---|---|---|
| Water Quality | Poor<br>Fair<br>Good<br>Excellent<br>Unknown | Increasing<br>About the same<br>Decreasing<br>Not Applicable<br>Unknown | Increasing<br>About the same<br>Decreasing<br>Not Applicable<br>Unknown | Poor<br>Fair<br>Good<br>Excellent<br>Unknown |
| Living Coral Cover | Poor<br>Fair<br>Good<br>Excellent<br>Unknown | Increasing<br>About the same<br>Decreasing<br>Not Applicable<br>Unknown | Increasing<br>About the same<br>Decreasing<br>Not Applicable<br>Unknown | Poor<br>Fair<br>Good<br>Excellent<br>Unknown |
| Reef Fish Populations | Poor<br>Fair<br>Good<br>Excellent<br>Unknown | Increasing<br>About the same<br>Decreasing<br>Not Applicable<br>Unknown | Increasing<br>About the same<br>Decreasing<br>Not Applicable<br>Unknown | Poor<br>Fair<br>Good<br>Excellent<br>Unknown |
| Harvested Reef Fish and Macroinvertebrates | Poor<br>Fair<br>Good<br>Excellent<br>Unknown | Increasing<br>About the same<br>Decreasing<br>Not Applicable<br>Unknown | Increasing<br>About the same<br>Decreasing<br>Not Applicable<br>Unknown | Poor<br>Fair<br>Good<br>Excellent<br>Unknown |
| Conservation Practices and Management Capacity | Poor<br>Fair<br>Good<br>Excellent<br>Unknown | Increasing<br>About the same<br>Decreasing<br>Not Applicable<br>Unknown | Increasing<br>About the same<br>Decreasing<br>Not Applicable<br>Unknown | Poor<br>Fair<br>Good<br>Excellent<br>Unknown |
| Benthic Mapping Products | Poor<br>Fair<br>Good<br>Excellent<br>Unknown | Increasing<br>About the same<br>Decreasing<br>Not Applicable<br>Unknown | Increasing<br>About the same<br>Decreasing<br>Not Applicable<br>Unknown | Poor<br>Fair<br>Good<br>Excellent<br>Unknown |

| Threats | The present level of this threat to the jurisdiction is... | Since the last Coral Report the trend in this threat is... | The long-term (10-25 yrs) trend in this threat is... | The jurisdictions ability to monitor and/or assess this threat is... |
|---|---|---|---|---|
| Coral Bleaching | Low<br>Medium<br>High<br>Absent<br>Unknown | Increasing<br>About the same<br>Decreasing<br>Not Applicable<br>Unknown | Increasing<br>About the same<br>Decreasing<br>Not Applicable<br>Unknown | Poor<br>Fair<br>Good<br>Excellent<br>Unknown |
| Coral Disease | Low<br>Medium<br>High<br>Absent<br>Unknown | Increasing<br>About the same<br>Decreasing<br>Not Applicable<br>Unknown | Increasing<br>About the same<br>Decreasing<br>Not Applicable<br>Unknown | Poor<br>Fair<br>Good<br>Excellent<br>Unknown |
| Tropical Storms | Low<br>Medium<br>High<br>Absent<br>Unknown | Increasing<br>About the same<br>Decreasing<br>Not Applicable<br>Unknown | Increasing<br>About the same<br>Decreasing<br>Not Applicable<br>Unknown | Poor<br>Fair<br>Good<br>Excellent<br>Unknown |
| Coastal Development | Low<br>Medium<br>High<br>Absent<br>Unknown | Increasing<br>About the same<br>Decreasing<br>Not Applicable<br>Unknown | Increasing<br>About the same<br>Decreasing<br>Not Applicable<br>Unknown | Poor<br>Fair<br>Good<br>Excellent<br>Unknown |
| Tourism and Recreation | Low<br>Medium<br>High<br>Absent<br>Unknown | Increasing<br>About the same<br>Decreasing<br>Not Applicable<br>Unknown | Increasing<br>About the same<br>Decreasing<br>Not Applicable<br>Unknown | Poor<br>Fair<br>Good<br>Excellent<br>Unknown |
| Commercial Fishing | Low<br>Medium<br>High<br>Absent<br>Unknown | Increasing<br>About the same<br>Decreasing<br>Not Applicable<br>Unknown | Increasing<br>About the same<br>Decreasing<br>Not Applicable<br>Unknown | Poor<br>Fair<br>Good<br>Excellent<br>Unknown |
| Subsistence and Recreational Fishing | Low<br>Medium<br>High<br>Absent<br>Unknown | Increasing<br>About the same<br>Decreasing<br>Not Applicable<br>Unknown | Increasing<br>About the same<br>Decreasing<br>Not Applicable<br>Unknown | Poor<br>Fair<br>Good<br>Excellent<br>Unknown |
| Vessel Damage | Low<br>Medium<br>High<br>Absent<br>Unknown | Increasing<br>About the same<br>Decreasing<br>Not Applicable<br>Unknown | Increasing<br>About the same<br>Decreasing<br>Not Applicable<br>Unknown | Poor<br>Fair<br>Good<br>Excellent<br>Unknown |
| Marine Debris | Low<br>Medium<br>High<br>Absent<br>Unknown | Increasing<br>About the same<br>Decreasing<br>Not Applicable<br>Unknown | Increasing<br>About the same<br>Decreasing<br>Not Applicable<br>Unknown | Poor<br>Fair<br>Good<br>Excellent<br>Unknown |
| Aquatic Invasive Species | Low<br>Medium<br>High<br>Absent<br>Unknown | Increasing<br>About the same<br>Decreasing<br>Not Applicable<br>Unknown | Increasing<br>About the same<br>Decreasing<br>Not Applicable<br>Unknown | Poor<br>Fair<br>Good<br>Excellent<br>Unknown |

# APPENDIX B: JURISDICTION PROFILES

The following tables are the products of a questionnaire circulated to report coordinators/writing team members in an effort to develop the National Summary chapter of this report. The questionnaire was divided into two parts. The first part addressed the condition of four target resource metrics (e.g., live coral, reef fish) using four multiple choice questions. The second part of the questionnaire addressed 10 key threats (e.g., disease, storms) that affect coral ecosystems. Information on the present status of Conservation and Management Capacity and Benthic Mapping Products was gathered in an attempt to better characterize the management ability to monitor key threats and utilize foundational mapping data products.

## U.S. VIRGIN ISLANDS

*Breakdown of overall average score for present condition, monitoring ability, three-year trend and long-term trend by four key resources and ten key threats.*

| | | PRESENT CONDITION | MONITORING ABILITY | 3 YEAR TREND | 10-25 YEAR TREND |
|---|---|---|---|---|---|
| Resources | Water Quality | GOOD | FAIR | DECREASING | DECREASING |
| | Living Coral Cover | POOR | GOOD | DECREASING | DECREASING |
| | Reef Fish Populations | POOR | FAIR | DECREASING | DECREASING |
| | Harvested Reef Fish and Macroinvertebrates | POOR | POOR | SAME | DECREASING |
| Threats | Climate Change and Coral Bleaching | HIGH | GOOD | INCREASING | INCREASING |
| | Coral Disease | HIGH | FAIR | INCREASING | INCREASING |
| | Tropical Storms | HIGH | GOOD | INCREASING | INCREASING |
| | Coastal Development | HIGH | POOR | INCREASING | INCREASING |
| | Tourism and Recreation | MED | POOR | INCREASING | INCREASING |
| | Commercial Fishing | HIGH | POOR | INCREASING | INCREASING |
| | Subsistence and Recreational Fishing | MED | POOR | UNKNOWN | UNKNOWN |
| | Vessel Damage | MED | FAIR | SAME | SAME |
| | Marine Debris | LOW | FAIR | SAME | INCREASING |
| | Aquatic Invasive Species | LOW | UNKNOWN | SAME | UNKNOWN |

*Assessment of present conservation and management capacity, ability, short-term and long-term trends. *Ability refers to efforts by the jurisdiction to evaluate the efficacy of management practices.*

| | PRESENT CONDITION | ABILITY* | 3 YEAR TREND | 10-25 YEAR TREND |
|---|---|---|---|---|
| **Conservation and Management Capacity** | POOR | POOR | DECREASING | DECREASING |

*Assessment of present availability of benthic mapping products, jurisdictional mapping ability, and short-term and long-term trends. *Ability refers to ability of jurisdiction to use the map products and tools available and apply them for research and conservation purposes.*

| | PRESENT CONDITION | ABILITY* | 3 YEAR TREND | 10-25 YEAR TREND |
|---|---|---|---|---|
| **Benthic Mapping Products** | GOOD | GOOD | INCREASING | INCREASING |

## PUERTO RICO

*Breakdown of overall average score for present condition, monitoring ability, three-year trend and long-term trend by four key resources and ten key threats.*

| | | PRESENT CONDITION | MONITORING ABILITY | 3 YEAR TREND | 10-25 YEAR TREND |
|---|---|---|---|---|---|
| **Resources** | Water Quality | POOR | FAIR | DECREASING | DECREASING |
| | Living Coral Cover | FAIR | GOOD | DECREASING | DECREASING |
| | Reef Fish Populations | FAIR | FAIR | DECREASING | DECREASING |
| | Harvested Reef Fish and Macroinvertebrates | FAIR | FAIR | DECREASING | DECREASING |
| **Threats** | Climate Change and Coral Bleaching | HIGH | GOOD | INCREASING | INCREASING |
| | Coral Disease | HIGH | GOOD | INCREASING | INCREASING |
| | Tropical Storms | LOW | FAIR | SAME | SAME |
| | Coastal Development | MED | FAIR | DECREASING | DECREASING |
| | Tourism and Recreation | LOW | FAIR | SAME | DECREASING |
| | Commercial Fishing | MED | POOR | SAME | INCREASING |
| | Subsistence and Recreational Fishing | MED | POOR | UNKNOWN | UNKNOWN |
| | Vessel Damage | LOW | GOOD | SAME | SAME |
| | Marine Debris | LOW | POOR | UNKNOWN | UNKNOWN |
| | Aquatic Invasive Species | LOW | POOR | SAME | UNKNOWN |

*Assessment of present conservation and management capacity, ability, short-term and long-term trends. *Ability refers to efforts by the jurisdiction to evaluate the efficacy of management practices.*

| | PRESENT CONDITION | ABILITY* | 3 YEAR TREND | 10-25 YEAR TREND |
|---|---|---|---|---|
| **Conservation and Management Capacity** | FAIR | FAIR | INCREASING | INCREASING |

*Assessment of present availability of benthic mapping products, jurisdictional mapping ability, and short-term and long-term trends. *Ability refers to ability of jurisdiction to use the map products and tools available and apply them for research and conservation purposes.*

| | PRESENT CONDITION | ABILITY* | 3 YEAR TREND | 10-25 YEAR TREND |
|---|---|---|---|---|
| **Benthic Mapping Products** | GOOD | GOOD | INCREASING | INCREASING |

## NAVASSA ISLAND

*Breakdown of overall average score for present condition, monitoring ability, three-year trend and long-term trend by four key resources and ten key threats.*

| | | PRESENT CONDITION | MONITORING ABILITY | 3 YEAR TREND | 10-25 YEAR TREND |
|---|---|---|---|---|---|
| **Resources** | Water Quality | EXCELLENT | POOR | UNKNOWN | UNKNOWN |
| | Living Coral Cover | FAIR | FAIR | DECREASING | DECREASING |
| | Reef Fish Populations | FAIR | FAIR | DECREASING | DECREASING |
| | Harvested Reef Fish and Macroinvertebrates | FAIR | FAIR | DECREASING | DECREASING |
| **Threats** | Climate Change and Coral Bleaching | HIGH | FAIR | INCREASING | INCREASING |
| | Coral Disease | HIGH | FAIR | SAME | INCREASING |
| | Tropical Storms | MED | POOR | SAME | SAME |
| | Coastal Development | LOW | POOR | SAME | SAME |
| | Tourism and Recreation | UNKNOWN | POOR | UNKNOWN | UNKNOWN |
| | Commercial Fishing | UNKNOWN | POOR | UNKNOWN | UNKNOWN |
| | Subsistence and Recreational Fishing | HIGH | FAIR | SAME | INCREASING |
| | Vessel Damage | ABSENT | FAIR | N/A | NA/ |
| | Marine Debris | MED | POOR | SAME | SAME |
| | Aquatic Invasive Species | LOW | POOR | INCREASING | SAME |

*Assessment of present conservation and management capacity, ability, short-term and long-term trends. *Ability refers to efforts by the jurisdiction to evaluate the efficacy of management practices.*

| | PRESENT CONDITION | ABILITY* | 3 YEAR TREND | 10-25 YEAR TREND |
|---|---|---|---|---|
| **Conservation and Management Capacity** | FAIR | POOR | SAME | SAME |

*Assessment of present availability of benthic mapping products, jurisdictional mapping ability, and short-term and long-term trends. *Ability refers to ability of jurisdiction to use the map products and tools available and apply them for research and conservation purposes.*

| | PRESENT CONDITION | ABILITY* | 3 YEAR TREND | 10-25 YEAR TREND |
|---|---|---|---|---|
| **Benthic Mapping Products** | GOOD | FAIR | INCREASING | INCREASING |

## SOUTHEAST FLORIDA

*Breakdown of overall average score for present condition, monitoring ability, three-year trend and long-term trend by four key resources and ten key threats.*

| | | PRESENT CONDITION | MONITORING ABILITY | 3 YEAR TREND | 10-25 YEAR TREND |
|---|---|---|---|---|---|
| **Resources** | Water Quality | POOR | POOR | SAME | DECREASING |
| | Living Coral Cover | FAIR | GOOD | SAME | DECREASING |
| | Reef Fish Populations | POOR | FAIR | SAME | DECREASING |
| | Harvested Reef Fish and Macroinvertebrates | FAIR | POOR | SAME | DECREASING |
| **Threats** | Climate Change and Coral Bleaching | LOW | FAIR | SAME | UNKNOWN |
| | Coral Disease | LOW | FAIR | SAME | UNKNOWN |
| | Tropical Storms | MED | FAIR | INCREASING | SAME |
| | Coastal Development | HIGH | FAIR | INCREASING | INCREASING |
| | Tourism and Recreation | HIGH | FAIR | INCREASING | INCREASING |
| | Commercial Fishing | MED | POOR | SAME | SAME |
| | Subsistence and Recreational Fishing | HIGH | POOR | INCREASING | INCREASING |
| | Vessel Damage | HIGH | FAIR | SAME | SAME |
| | Marine Debris | MED | POOR | SAME | INCREASING |
| | Aquatic Invasive Species | MED | POOR | SAME | SAME |

*Assessment of present conservation and management capacity, ability, short-term and long-term trends. *Ability refers to efforts by the jurisdiction to evaluate the efficacy of management practices.*

| | PRESENT CONDITION | ABILITY* | 3 YEAR TREND | 10-25 YEAR TREND |
|---|---|---|---|---|
| **Conservation and Management Capacity** | FAIR | FAIR | INCREASING | INCREASING |

*Assessment of present availability of benthic mapping products, jurisdictional mapping ability, and short-term and long-term trends. *Ability refers to ability of jurisdiction to use the map products and tools available and apply them for research and conservation purposes.*

| | PRESENT CONDITION | ABILITY* | 3 YEAR TREND | 10-25 YEAR TREND |
|---|---|---|---|---|
| **Benthic Mapping Products** | FAIR | GOOD | INCREASING | INCREASING |

## FLORIDA KEYS

*Breakdown of overall average score for present condition, monitoring ability, three-year trend and long-term trend by four key resources and ten key threats.*

| | | PRESENT CONDITION | MONITORING ABILITY | 3 YEAR TREND | 10-25 YEAR TREND |
|---|---|---|---|---|---|
| **Resources** | Water Quality | FAIR | GOOD | SAME | SAME |
| | Living Coral Cover | POOR | GOOD | SAME | DECREASING |
| | Reef Fish Populations | FAIR | EXCELLENT | SAME | SAME |
| | Harvested Reef Fish and Macroinvertebrates | POOR | EXCELLENT | SAME | DECREASING |
| **Threats** | Climate Change and Coral Bleaching | MED | GOOD | SAME | INCREASING |
| | Coral Disease | HIGH | EXCELLENT | SAME | INCREASING |
| | Tropical Storms | HIGH | GOOD | SAME | INCREASING |
| | Coastal Development | HIGH | GOOD | SAME | INCREASING |
| | Tourism and Recreation | HIGH | GOOD | SAME | INCREASING |
| | Commercial Fishing | HIGH | GOOD | SAME | SAME |
| | Subsistence and Recreational Fishing | HIGH | FAIR | SAME | INCREASING |
| | Vessel Damage | MED | EXCELLENT | SAME | SAME |
| | Marine Debris | MED | GOOD | SAME | UNKNOWN |
| | Aquatic Invasive Species | MED | GOOD | SAME | INCREASING |

*Assessment of present conservation and management capacity, ability, short-term and long-term trends. *Ability refers to efforts by the jurisdiction to evaluate the efficacy of management practices.*

| | PRESENT CONDITION | ABILITY* | 3 YEAR TREND | 10-25 YEAR TREND |
|---|---|---|---|---|
| **Conservation and Management Capacity** | GOOD | EXCELLENT | SAME | INCREASING |

*Assessment of present availability of benthic mapping products, jurisdictional mapping ability, and short-term and long-term trends. *Ability refers to ability of jurisdiction to use the map products and tools available and apply them for research and conservation purposes.*

| | PRESENT CONDITION | ABILITY* | 3 YEAR TREND | 10-25 YEAR TREND |
|---|---|---|---|---|
| **Benthic Mapping Products** | FAIR | FAIR | INCREASING | INCREASING |

## FLOWER GARDEN BANKS, STETSON BANK AND OTHER BANKS IN THE NORTHWESTERN GULF OF MEXICO

*Breakdown of overall average score for present condition, monitoring ability, three-year trend and long-term trend by four key resources and ten key threats.*

| | | PRESENT CONDITION | MONITORING ABILITY | 3 YEAR TREND | 10-25 YEAR TREND |
|---|---|---|---|---|---|
| Resources | Water Quality | GOOD | FAIR | DECREASING | UNKNOWN |
| | Living Coral Cover | EXCELLENT | GOOD | SAME | SAME |
| | Reef Fish Populations | GOOD | FAIR | SAME | UNKNOWN |
| | Harvested Reef Fish and Macroinvertebrates | GOOD | POOR | SAME | UNKNOWN |
| Threats | Climate Change and Coral Bleaching | LOW | GOOD | INCREASING | INCREASING |
| | Coral Disease | LOW | GOOD | INCREASING | INCREASING |
| | Tropical Storms | HIGH | GOOD | SAME | SAME |
| | Coastal Development | ABSENT | N/A | N/A | N/A |
| | Tourism and Recreation | LOW | FAIR | SAME | INCREASING |
| | Commercial Fishing | UNKNOWN | POOR | UNKNOWN | UNKNOWN |
| | Subsistence and Recreational Fishing | UNKNOWN | POOR | INCREASING | INCREASING |
| | Vessel Damage | LOW | FAIR | SAME | SAME |
| | Marine Debris | MED | FAIR | SAME | INCREASING |
| | Aquatic Invasive Species | LOW | FAIR | INCREASING | INCREASING |

*Assessment of present conservation and management capacity, ability, short-term and long-term trends. *Ability refers to efforts by the jurisdiction to evaluate the efficacy of management practices.*

| | PRESENT CONDITION | ABILITY* | 3 YEAR TREND | 10-25 YEAR TREND |
|---|---|---|---|---|
| **Conservation and Management Capacity** | GOOD | GOOD | INCREASING | INCREASING |

*Assessment of present availability of benthic mapping products, jurisdictional mapping ability, and short-term and long-term trends. *Ability refers to ability of jurisdiction to use the map products and tools available and apply them for research and conservation purposes.*

| | PRESENT CONDITION | ABILITY* | 3 YEAR TREND | 10-25 YEAR TREND |
|---|---|---|---|---|
| **Benthic Mapping Products** | GOOD | EXCELLENT* | INCREASING | INCREASING |

## MAIN HAWAIIAN ISLANDS

*Breakdown of overall average score for present condition, monitoring ability, three-year trend and long-term trend by four key resources and ten key threats.*

| | | PRESENT CONDITION | MONITORING ABILITY | 3 YEAR TREND | 10-25 YEAR TREND |
|---|---|---|---|---|---|
| Resources | Water Quality | GOOD | FAIR | SAME | DECREASING |
| | Living Coral Cover | GOOD | FAIR | DECREASING | DECREASING |
| | Reef Fish Populations | FAIR | FAIR | DECREASING | DECREASING |
| | Harvested Reef Fish and Macroinvertebrates | POOR | FAIR | DECREASING | DECREASING |
| Threats | Climate Change and Coral Bleaching | MED | FAIR | INCREASING | INCREASING |
| | Coral Disease | MED | FAIR | INCREASING | INCREASING |
| | Tropical Storms | LOW | GOOD | SAME | SAME |
| | Coastal Development | HIGH | FAIR | INCREASING | INCREASING |
| | Tourism and Recreation | HIGH | FAIR | INCREASING | INCREASING |
| | Commercial Fishing | HIGH | POOR | INCREASING | SAME |
| | Subsistence and Recreational Fishing | HIGH | POOR | INCREASING | INCREASING |
| | Vessel Damage | LOW | FAIR | INCREASING | INCREASING |
| | Marine Debris | HIGH | FAIR | INCREASING | INCREASING |
| | Aquatic Invasive Species | HIGH | FAIR | INCREASING | INCREASING |

*Assessment of present conservation and management capacity, ability, short-term and long-term trends. *Ability refers to efforts by the jurisdiction to evaluate the efficacy of management practices.*

| | PRESENT CONDITION | ABILITY* | 3 YEAR TREND | 10-25 YEAR TREND |
|---|---|---|---|---|
| **Conservation and Management Capacity** | FAIR | FAIR | INCREASING | SAME |

*Assessment of present availability of benthic mapping products, jurisdictional mapping ability, and short-term and long-term trends. *Ability refers to ability of jurisdiction to use the map products and tools available and apply them for research and conservation purposes.*

| | PRESENT CONDITION | ABILITY* | 3 YEAR TREND | 10-25 YEAR TREND |
|---|---|---|---|---|
| **Benthic Mapping Products** | GOOD | GOOD | INCREASING | INCREASING |

## NORTHWESTERN HAWAIIAN ISLANDS

*Breakdown of overall average score for present condition, monitoring ability, three-year trend and long-term trend by four key resources and ten key threats.*

| | | PRESENT CONDITION | MONITORING ABILITY | 3 YEAR TREND | 10-25 YEAR TREND |
|---|---|---|---|---|---|
| Resources | Water Quality | EXCELLENT | FAIR | SAME | SAME |
| | Living Coral Cover | EXCELLENT | FAIR | SAME | SAME |
| | Reef Fish Populations | EXCELLENT | FAIR | SAME | SAME |
| | Harvested Reef Fish and Macroinvertebrates | EXCELLENT | FAIR | SAME | SAME |
| Threats | Climate Change and Coral Bleaching | MED | FAIR | INCREASING | INCREASING |
| | Coral Disease | MED | FAIR | INCREASING | INCREASING |
| | Tropical Storms | LOW | FAIR | SAME | SAME |
| | Coastal Development | LOW | GOOD | SAME | SAME |
| | Tourism and Recreation | LOW | FAIR | SAME | INCREASING |
| | Commercial Fishing | LOW | FAIR | DECREASING | DECREASING |
| | Subsistence and Recreational Fishing | LOW | POOR | INCREASING | INCREASING |
| | Vessel Damage | LOW | FAIR | SAME | INCREASING |
| | Marine Debris | MED | GOOD | INCREASING | INCREASING |
| | Aquatic Invasive Species | MED | POOR | INCREASING | INCREASING |

*Assessment of present conservation and management capacity, ability, short-term and long-term trends. *Ability refers to efforts by the jurisdiction to evaluate the efficacy of management practices.*

| | PRESENT CONDITION | ABILITY* | 3 YEAR TREND | 10-25 YEAR TREND |
|---|---|---|---|---|
| **Conservation and Management Capacity** | GOOD | GOOD | INCREASING | INCREASING |

*Assessment of present availability of benthic mapping products, jurisdictional mapping ability, and short-term and long-term trends. *Ability refers to ability of jurisdiction to use the map products and tools available and apply them for research and conservation purposes.*

| | PRESENT CONDITION | ABILITY* | 3 YEAR TREND | 10-25 YEAR TREND |
|---|---|---|---|---|
| **Benthic Mapping Products** | FAIR | GOOD | INCREASING | INCREASING |

## AMERICAN SAMOA

*Breakdown of overall average score for present condition, monitoring ability, three-year trend and long-term trend by four key resources and ten key threats.*

| | | PRESENT CONDITION | MONITORING ABILITY | 3 YEAR TREND | 10-25 YEAR TREND |
|---|---|---|---|---|---|
| **Resources** | Water Quality | GOOD | GOOD | INCREASING | SAME |
| | Living Coral Cover | GOOD | GOOD | SAME | DECREASING |
| | Reef Fish Populations | GOOD/FAIR | GOOD | SAME | SAME |
| | Harvested Reef Fish and Macroinvertebrates | GOOD/FAIR | GOOD | SAME | SAME |
| **Threats** | Climate Change and Coral Bleaching | MED | GOOD | SAME | INCREASING |
| | Coral Disease | LOW | FAIR | SAME | UNKNOWN |
| | Tropical Storms | MED | GOOD | SAME | SAME |
| | Coastal Development | HIGH | GOOD | INCREASING | INCREASING |
| | Tourism and Recreation | LOW | FAIR | SAME | INCREASING |
| | Commercial Fishing | LOW | GOOD | SAME | DECREASING |
| | Subsistence and Recreational Fishing | LOW | GOOD | SAME | DECREASING |
| | Vessel Damage | LOW | FAIR | SAME | DECREASING |
| | Marine Debris | MED | FAIR | SAME | INCREASING |
| | Aquatic Invasive Species | LOW | FAIR | SAME | INCREASING |

*Assessment of present conservation and management capacity, ability, short-term and long-term trends. *Ability refers to efforts by the jurisdiction to evaluate the efficacy of management practices.*

| | PRESENT CONDITION | ABILITY* | 3 YEAR TREND | 10-25 YEAR TREND |
|---|---|---|---|---|
| **Conservation and Management Capacity** | GOOD | GOOD | INCREASING | INCREASING |

*Assessment of present availability of benthic mapping products, jurisdictional mapping ability, and short-term and long-term trends. *Ability refers to ability of jurisdiction to use the map products and tools available and apply them for research and conservation purposes.*

| | PRESENT CONDITION | ABILITY* | 3 YEAR TREND | 10-25 YEAR TREND |
|---|---|---|---|---|
| **Benthic Mapping Products** | EXCELLENT | GOOD | INCREASING | INCREASING |

## PACIFIC REMOTE ISLAND AREAS

*Breakdown of overall average score for present condition, monitoring ability, three-year trend and long-term trend by four key resources and ten key threats.*

| | | PRESENT CONDITION | MONITORING ABILITY | 3 YEAR TREND | 10-25 YEAR TREND |
|---|---|---|---|---|---|
| Resources | Water Quality | EXCELLENT | FAIR | SAME | UNKNOWN |
| | Living Coral Cover | GOOD | FAIR | SAME | UNKNOWN |
| | Reef Fish Populations | EXCELLENT | FAIR | SAME | SAME |
| | Harvested Reef Fish and Macroinvertebrates | UNKNOWN | FAIR | N/A | N/A |
| Threats | Climate Change and Coral Bleaching | LOW | FAIR | SAME | UNKNOWN |
| | Coral Disease | LOW | FAIR | SAME | UNKNOWN |
| | Tropical Storms | LOW | FAIR | SAME | SAME |
| | Coastal Development | LOW | EXCELLENT | DECREASING | SAME |
| | Tourism and Recreation | LOW | GOOD | SAME | SAME |
| | Commercial Fishing | LOW | FAIR | SAME | SAME |
| | Subsistence and Recreational Fishing | LOW | FAIR | SAME | SAME |
| | Vessel Damage | MED | FAIR | SAME | SAME |
| | Marine Debris | LOW | FAIR | SAME | SAME |
| | Aquatic Invasive Species | LOW | FAIR | SAME | SAME |

*Assessment of present conservation and management capacity, ability, short-term and long-term trends. *Ability refers to efforts by the jurisdiction to evaluate the efficacy of management practices.*

| | PRESENT CONDITION | ABILITY* | 3 YEAR TREND | 10-25 YEAR TREND |
|---|---|---|---|---|
| **Conservation and Management Capacity** | GOOD | FAIR | INCREASING | INCREASING |

*Assessment of present availability of benthic mapping products, jurisdictional mapping ability, and short-term and long-term trends. *Ability refers to ability of jurisdiction to use the map products and tools available and apply them for research and conservation purposes.*

| | PRESENT CONDITION | ABILITY* | 3 YEAR TREND | 10-25 YEAR TREND |
|---|---|---|---|---|
| **Benthic Mapping Products** | EXCELLENT | GOOD | INCREASING | INCREASING |

## REPUBLIC OF THE MARSHALL ISLANDS

*Breakdown of overall average score for present condition, monitoring ability, three-year trend and long-term trend by four key resources and ten key threats.*

| | | PRESENT CONDITION | MONITORING ABILITY | 3 YEAR TREND | 10-25 YEAR TREND |
|---|---|---|---|---|---|
| **Resources** | Water Quality | EXCELLENT | POOR | SAME | SAME |
| | Living Coral Cover | EXCELLENT | GOOD | SAME | SAME |
| | Reef Fish Populations | GOOD | GOOD | SAME | DECREASING |
| | Harvested Reef Fish and Macroinvertebrates | FAIR | GOOD | DECREASING | DECREASING |
| **Threats** | Climate Change and Coral Bleaching | MED | GOOD | INCREASING | INCREASING |
| | Coral Disease | MED | GOOD | INCREASING | INCREASING |
| | Tropical Storms | LOW | GOOD | SAME | SAME |
| | Coastal Development | MED | GOOD | INCREASING | INCREASING |
| | Tourism and Recreation | LOW | GOOD | INCREASING | INCREASING |
| | Commercial Fishing | MED | FAIR | INCREASING | INCREASING |
| | Subsistence and Recreational Fishing | HIGH | FAIR | INCREASING | INCREASING |
| | Vessel Damage | LOW | GOOD | SAME | INCREASING |
| | Marine Debris | MED | FAIR | INCREASING | INCREASING |
| | Aquatic Invasive Species | LOW | POOR | SAME | UNKNOWN |

*Assessment of present conservation and management capacity, ability, short-term and long-term trends. *Ability refers to efforts by the jurisdiction to evaluate the efficacy of management practices.*

| | PRESENT CONDITION | ABILITY* | 3 YEAR TREND | 10-25 YEAR TREND |
|---|---|---|---|---|
| **Conservation and Management Capacity** | POOR | FAIR | SAME | INCREASING |

*Assessment of present availability of benthic mapping products, jurisdictional mapping ability, and short-term and long-term trends. *Ability refers to ability of jurisdiction to use the map products and tools available and apply them for research and conservation purposes.*

| | PRESENT CONDITION | ABILITY* | 3 YEAR TREND | 10-25 YEAR TREND |
|---|---|---|---|---|
| **Benthic Mapping Products** | POOR | POOR | SAME | SAME |

## FEDERATED STATES OF MICRONESIA

*Breakdown of overall average score for present condition, monitoring ability, three-year trend and long-term trend by four key resources and ten key threats.*

| | | PRESENT CONDITION | MONITORING ABILITY | 3 YEAR TREND | 10-25 YEAR TREND |
|---|---|---|---|---|---|
| **Resources** | Water Quality | GOOD | FAIR | SAME | DECREASING |
| | Living Coral Cover | GOOD | FAIR | SAME | DECREASING |
| | Reef Fish Populations | GOOD | FAIR | DECREASING | DECREASING |
| | Harvested Reef Fish and Macroinvertebrates | FAIR | FAIR | (NO ANSWER PROVIDED) | DECREASING |
| **Threats** | Climate Change and Coral Bleaching | LOW | GOOD | SAME | INCREASING |
| | Coral Disease | LOW | FAIR | SAME | INCREASING |
| | Tropical Storms | HIGH | GOOD | INCREASING | INCREASING |
| | Coastal Development | HIGH | GOOD | INCREASING | INCREASING |
| | Tourism and Recreation | MED | FAIR | INCREASING | INCREASING |
| | Commercial Fishing | HIGH | FAIR | INCREASING | INCREASING |
| | Subsistence and Recreational Fishing | HIGH | GOOD | INCREASING | INCREASING |
| | Vessel Damage | MED | FAIR | INCREASING | INCREASING |
| | Marine Debris | HIGH | GOOD | INCREASING | INCREASING |
| | Aquatic Invasive Species | MED | FAIR | INCREASING | INCREASING |

*Assessment of present conservation and management capacity, ability, short-term and long-term trends. *Ability refers to efforts by the jurisdiction to evaluate the efficacy of management practices.*

| | PRESENT CONDITION | ABILITY* | 3 YEAR TREND | 10-25 YEAR TREND |
|---|---|---|---|---|
| **Conservation and Management Capacity** | GOOD | GOOD | INCREASING | INCREASING |

*Assessment of present availability of benthic mapping products, jurisdictional mapping ability, and short-term and long-term trends. *Ability refers to ability of jurisdiction to use the map products and tools available and apply them for research and conservation purposes.*

| | PRESENT CONDITION | ABILITY* | 3 YEAR TREND | 10-25 YEAR TREND |
|---|---|---|---|---|
| **Benthic Mapping Products** | POOR | UNKNOWN | INCREASING | INCREASING |

## COMMONWEALTH OF THE NORTHERN MARIANA ISLANDS

*Breakdown of overall average score for present condition, monitoring ability, three-year trend and long-term trend by four key resources and ten key threats.*

| | | PRESENT CONDITION | MONITORING ABILITY | 3 YEAR TREND | 10-25 YEAR TREND |
|---|---|---|---|---|---|
| **Resources** | Water Quality | GOOD | GOOD | DECREASING | DECREASING |
| | Living Coral Cover | GOOD | EXCELLENT | INCREASING | DECREASING |
| | Reef Fish Populations | FAIR | FAIR | SAME | SAME |
| | Harvested Reef Fish and Macroinvertebrates | FAIR | FAIR | SAME | SAME |
| **Threats** | Climate Change and Coral Bleaching | MED | GOOD | SAME | INCREASING |
| | Coral Disease | LOW | FAIR | SAME | SAME |
| | Tropical Storms | MED | GOOD | SAME | SAME |
| | Coastal Development | MED | EXCELLENT | SAME | DECREASING |
| | Tourism and Recreation | MED | FAIR | INCREASING | INCREASING |
| | Commercial Fishing | MED | FAIR | SAME | DECREASING |
| | Subsistence and Recreational Fishing | MED | FAIR | INCREASING | INCREASING |
| | Vessel Damage | LOW | FAIR | SAME | SAME |
| | Marine Debris | MED | FAIR | SAME | INCREASING |
| | Aquatic Invasive Species | LOW | FAIR | INCREASING | SAME |

*Assessment of present conservation and management capacity, ability, short-term and long-term trends. *Ability refers to efforts by the jurisdiction to evaluate the efficacy of management practices.*

| | PRESENT CONDITION | ABILITY* | 3 YEAR TREND | 10-25 YEAR TREND |
|---|---|---|---|---|
| **Conservation and Management Capacity** | GOOD | GOOD | SAME | INCREASING |

*Assessment of present availability of benthic mapping products, jurisdictional mapping ability, and short-term and long-term trends. *Ability refers to ability of jurisdiction to use the map products and tools available and apply them for research and conservation purposes.*

| | PRESENT CONDITION | ABILITY* | 3 YEAR TREND | 10-25 YEAR TREND |
|---|---|---|---|---|
| **Benthic Mapping Products** | GOOD | GOOD | INCREASING | INCREASING |

## GUAM

*Breakdown of overall average score for present condition, monitoring ability, three-year trend and long-term trend by four key resources and ten key threats.*

| | | PRESENT CONDITION | MONITORING ABILITY | 3 YEAR TREND | 10-25 YEAR TREND |
|---|---|---|---|---|---|
| Resources | Water Quality | GOOD | GOOD | SAME | DECREASING |
| | Living Coral Cover | FAIR | GOOD | DECREASING | DECREASING |
| | Reef Fish Populations | FAIR | GOOD | SAME | DECREASING |
| | Harvested Reef Fish and Macroinvertebrates | FAIR | GOOD | SAME | DECREASING |
| Threats | Climate Change and Coral Bleaching | MED | FAIR | INCREASING | INCREASING |
| | Coral Disease | LOW | GOOD | INCREASING | INCREASING |
| | Tropical Storms | MED | GOOD | SAME | SAME |
| | Coastal Development | HIGH | GOOD | INCREASING | INCREASING |
| | Tourism and Recreation | MED | FAIR | INCREASING | INCREASING |
| | Commercial Fishing | MED | FAIR | SAME | SAME |
| | Subsistence and Recreational Fishing | MED | GOOD | SAME | INCREASING |
| | Vessel Damage | MED | GOOD | SAME | INCREASING |
| | Marine Debris | MED | FAIR | SAME | INCREASING |
| | Aquatic Invasive Species | LOW | POOR | INCREASING | INCREASING |

*Assessment of present conservation and management capacity, ability, short-term and long-term trends. *Ability refers to efforts by the jurisdiction to evaluate the efficacy of management practices.*

| | PRESENT CONDITION | ABILITY* | 3 YEAR TREND | 10-25 YEAR TREND |
|---|---|---|---|---|
| **Conservation and Management Capacity** | GOOD | GOOD | SAME | INCREASING |

*Assessment of present availability of benthic mapping products, jurisdictional mapping ability, and short-term and long-term trends. *Ability refers to ability of jurisdiction to use the map products and tools available and apply them for research and conservation purposes.*

| | PRESENT CONDITION | ABILITY* | 3 YEAR TREND | 10-25 YEAR TREND |
|---|---|---|---|---|
| **Benthic Mapping Products** | GOOD | GOOD | INCREASING | INCREASING |

## REPUBLIC OF PALAU

*Breakdown of overall average score for present condition, monitoring ability, three-year trend and long-term trend by four key resources and ten key threats.*

| | | PRESENT CONDITION | MONITORING ABILITY | 3 YEAR TREND | 10-25 YEAR TREND |
|---|---|---|---|---|---|
| Resources | Water Quality | GOOD | FAIR | DECREASING | DECREASING |
| | Living Coral Cover | GOOD | GOOD | INCREASING | INCREASING |
| | Reef Fish Populations | GOOD | FAIR | SAME | SAME |
| | Harvested Reef Fish and Macroinvertebrates | FAIR | FAIR | DECREASING | DECREASING |
| Threats | Climate Change and Coral Bleaching | MED | FAIR | UNKNOWN | INCREASING |
| | Coral Disease | LOW | POOR | UNKNOWN | INCREASING |
| | Tropical Storms | LOW | GOOD | SAME | INCREASING |
| | Coastal Development | HIGH | FAIR | INCREASING | INCREASING |
| | Tourism and Recreation | HIGH | FAIR | INCREASING | INCREASING |
| | Commercial Fishing | HIGH | POOR | INCREASING | INCREASING |
| | Subsistence and Recreational Fishing | MED | POOR | INCREASING | INCREASING |
| | Vessel Damage | MED | GOOD | INCREASING | INCREASING |
| | Marine Debris | MED | FAIR | INCREASING | INCREASING |
| | Aquatic Invasive Species | MED | POOR | INCREASING | INCREASING |

*Assessment of present conservation and management capacity, ability, short-term and long-term trends. *Ability refers to efforts by the jurisdiction to evaluate the efficacy of management practices.*

| | PRESENT CONDITION | ABILITY* | 3 YEAR TREND | 10-25 YEAR TREND |
|---|---|---|---|---|
| **Conservation and Management Capacity** | GOOD | FAIR | INCREASING | INCREASING |

*Assessment of present availability of benthic mapping products, jurisdictional mapping ability, and short-term and long-term trends. *Ability refers to ability of jurisdiction to use the map products and tools available and apply them for research and conservation purposes.*

| | PRESENT CONDITION | ABILITY* | 3 YEAR TREND | 10-25 YEAR TREND |
|---|---|---|---|---|
| **Benthic Mapping Products** | FAIR* | FAIR | SAME* | INCREASING |

United States Department of Commerce

Carlos M. Gutierrez
*Secretary*

National Oceanic and Atmospheric Administration

Vice Admiral Conrad C. Lautenbacher, Jr. USN (Ret.)
*Under Secretary of Commerce for Oceans and Atmosphere*

NOAA's Ocean Service

John H. Dunnigan
*Assistant Administrator for Ocean Service and Coastal Zone Management*